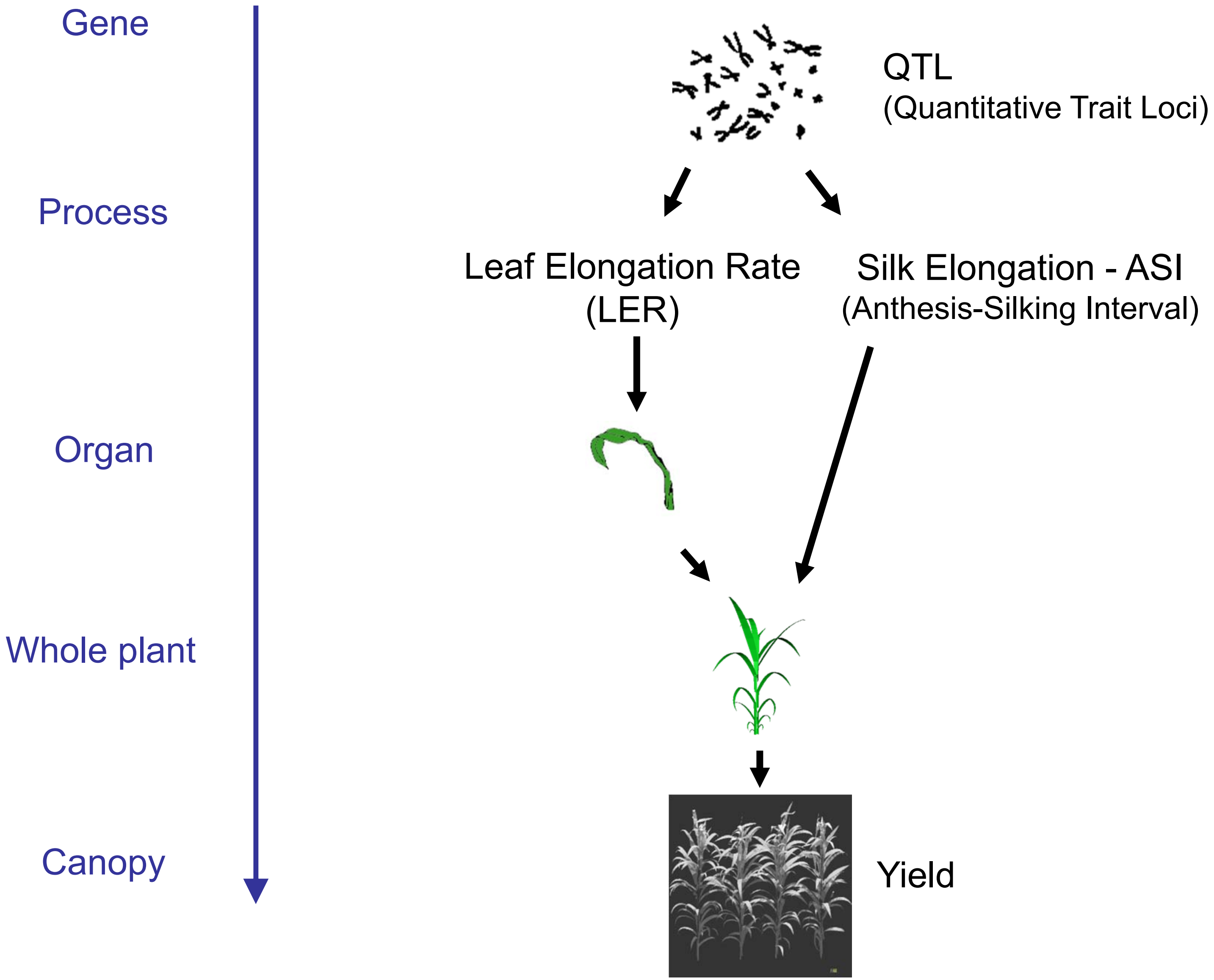
Trait dissection
using a modelling framework
- Examples in maize and wheat -

Karine Chenu *et al.*

QAAFI, The University of Queensland, Toowoomba

A gene-to-phenotype modelling approach



A gene-to-phenotype modelling approach

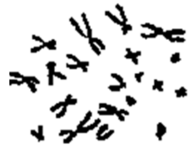
Gene

Process

Organ

Whole plant

Canopy

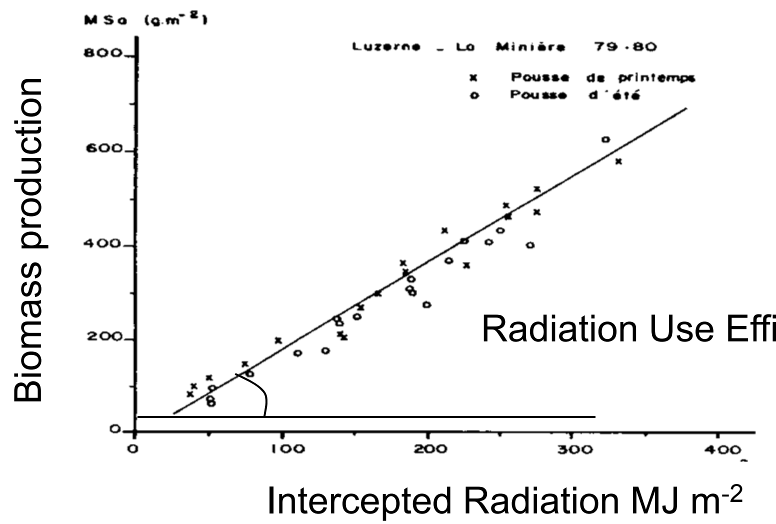


QTL
(Quantitative Trait Loci)

Leaf Elongation Rate
(LER)

Silk Elongation - ASI
(Anthesis-Silking Interval)

Leaf growth for light interception



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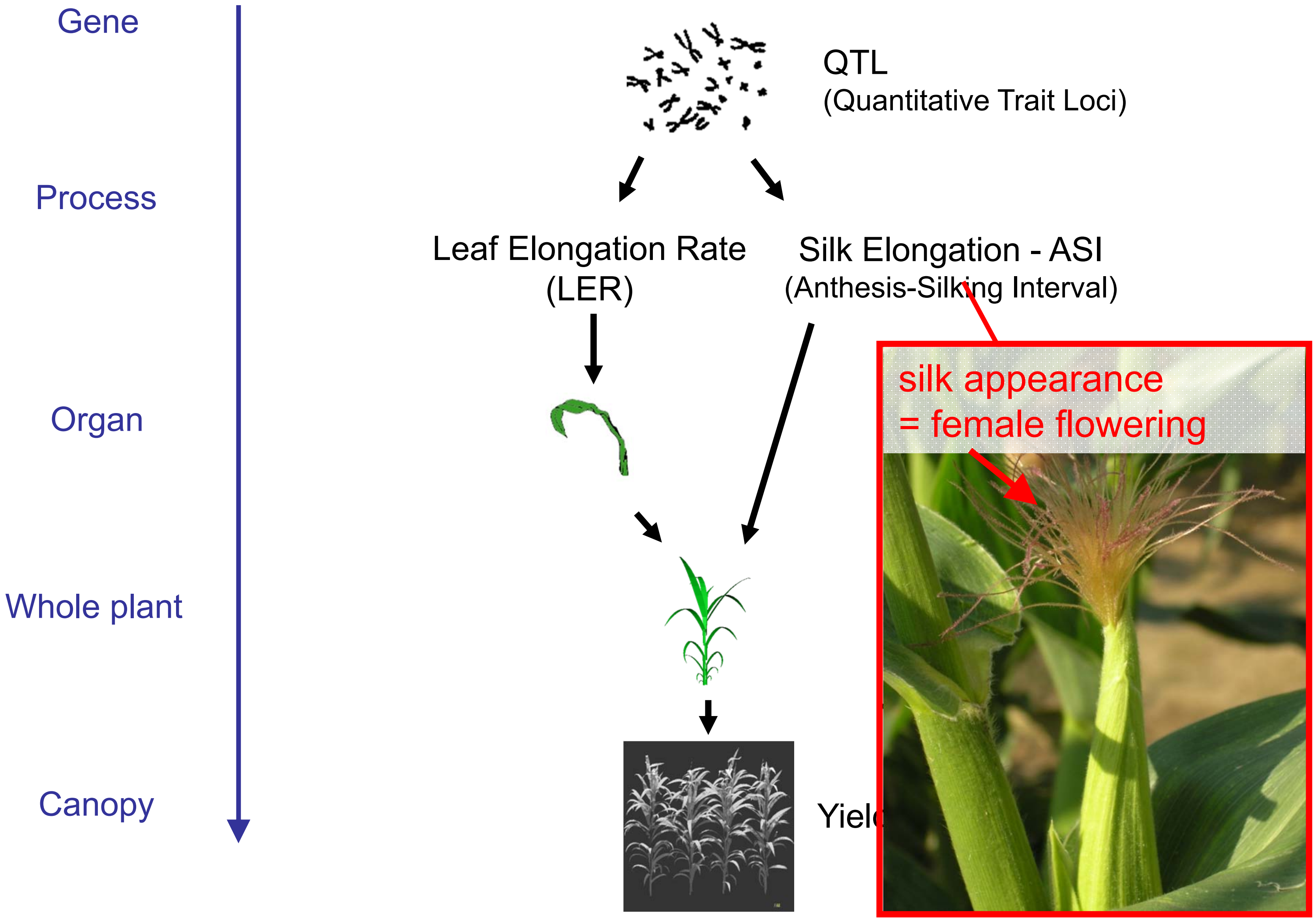

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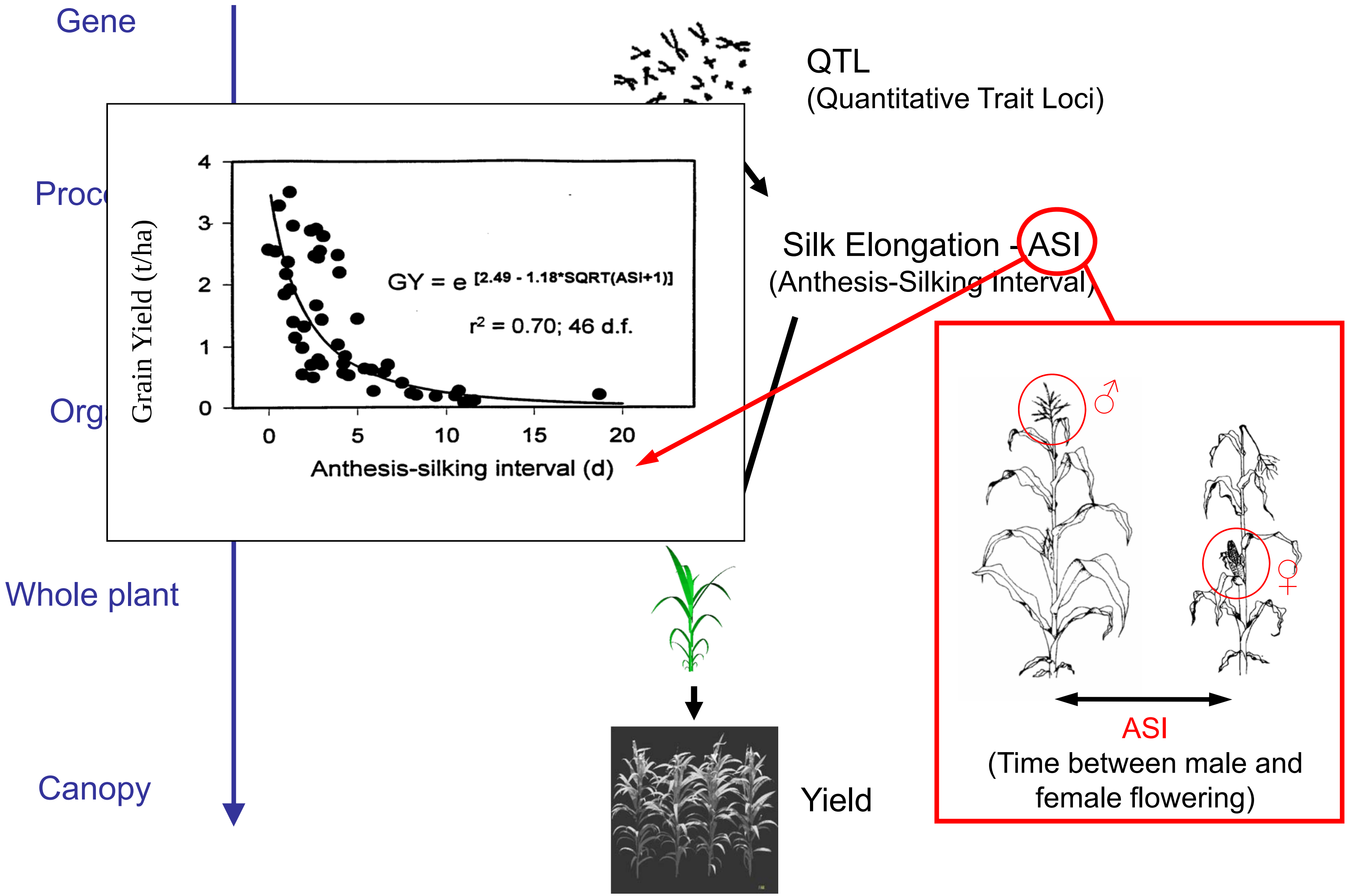

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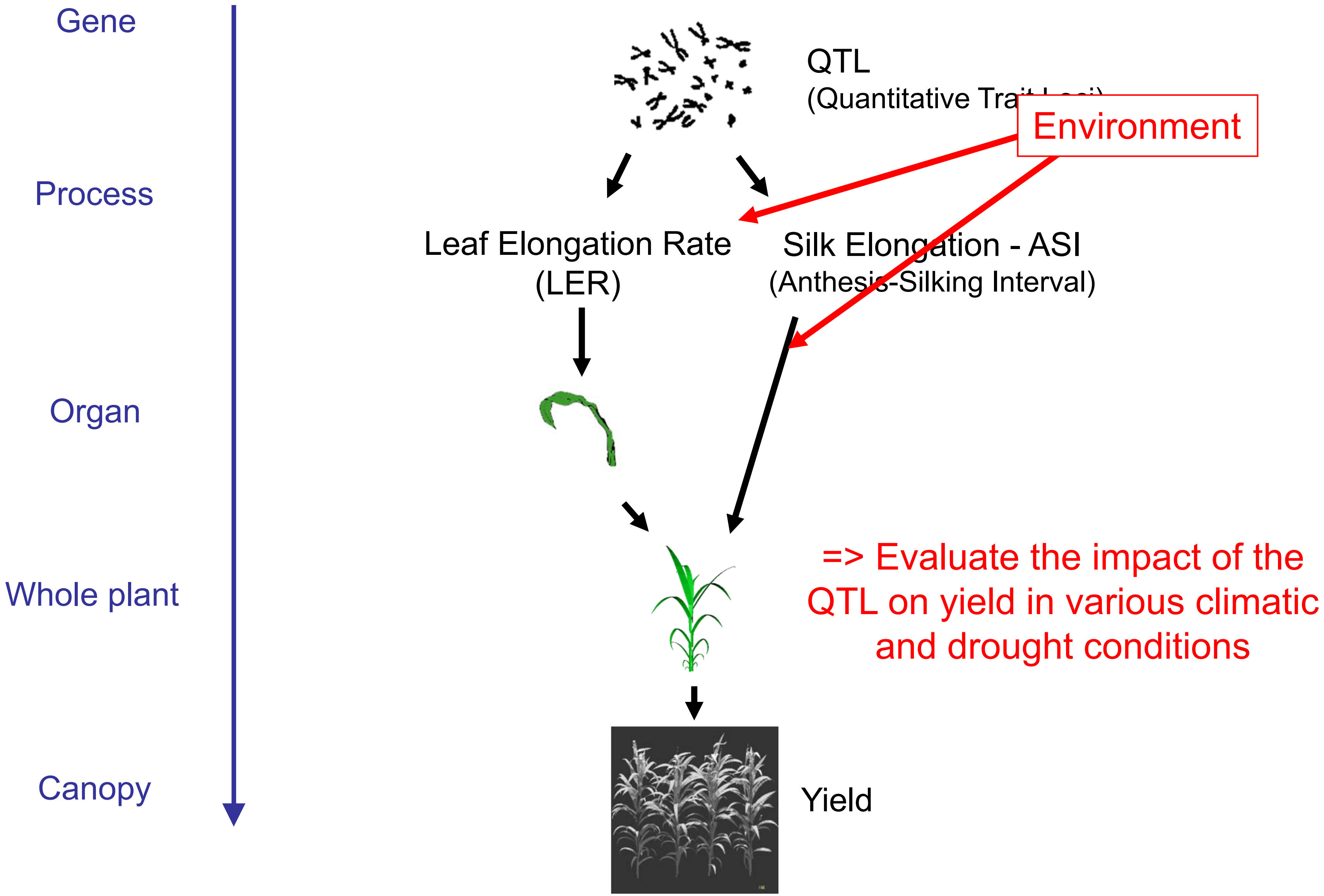
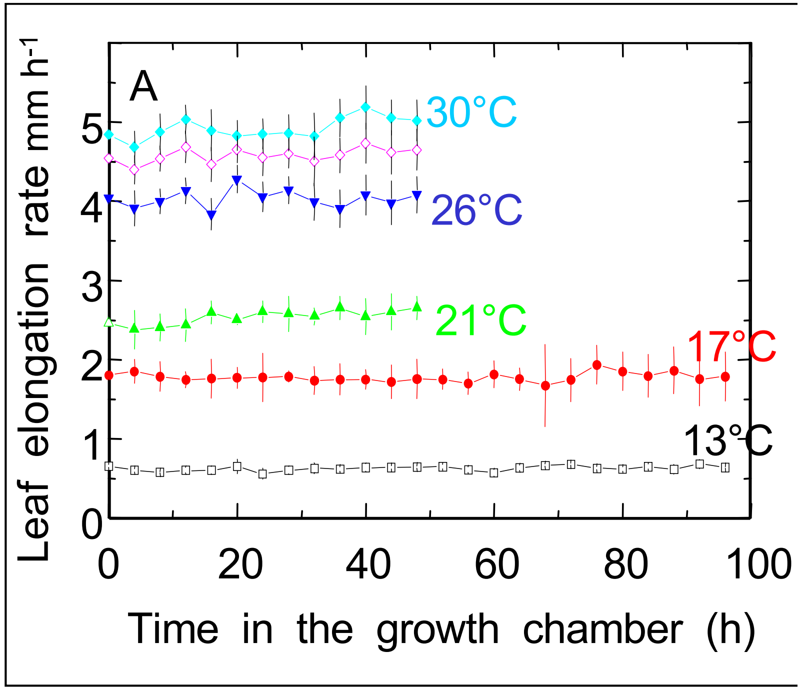


Leaf expansion in Maize

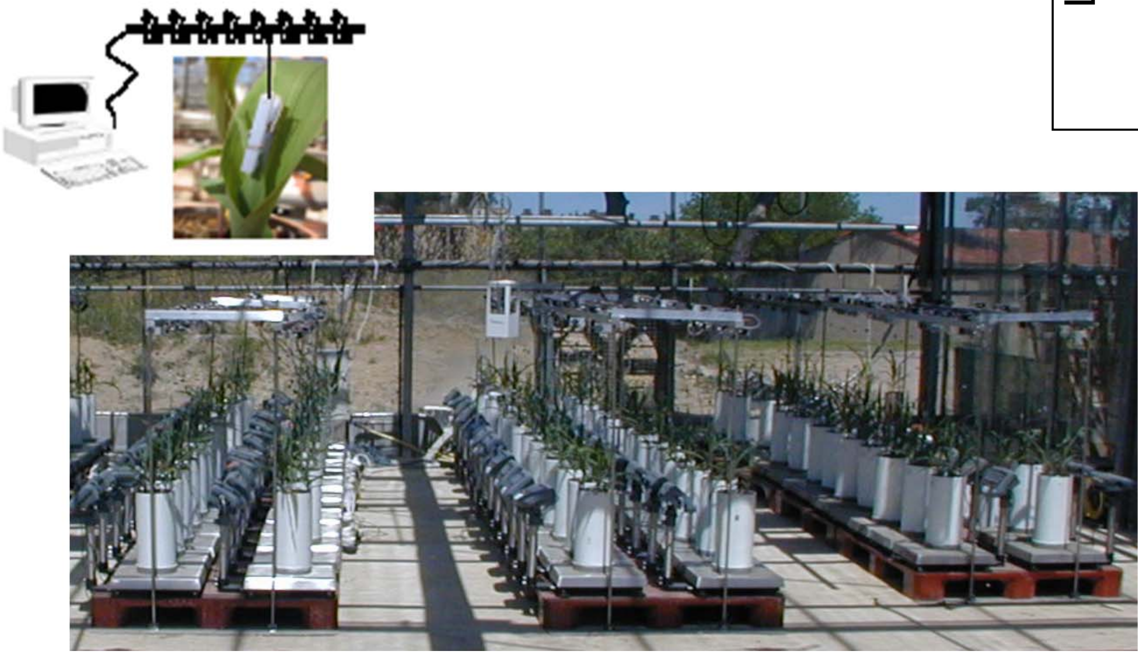
Monocot : period of linear expansion

Possibility to follow leaf expansion rate with a 15 minutes definition

Experimental set-up for 360 plants together

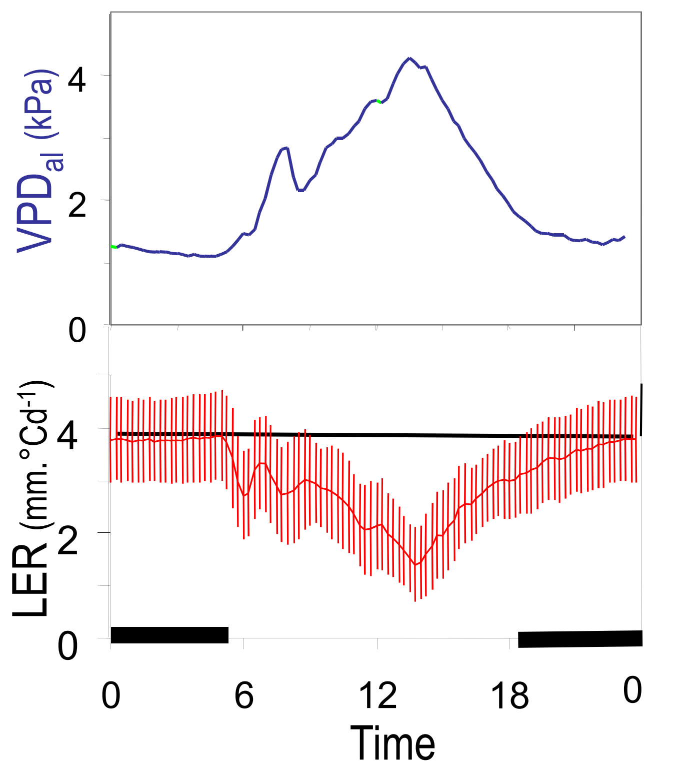


Ben Haj Salah & Tardieu 19



Leaf expansion in Maize under drought conditions

- Instantaneous response of leaf expansion to an environmental stress



Sadok et al. submitted

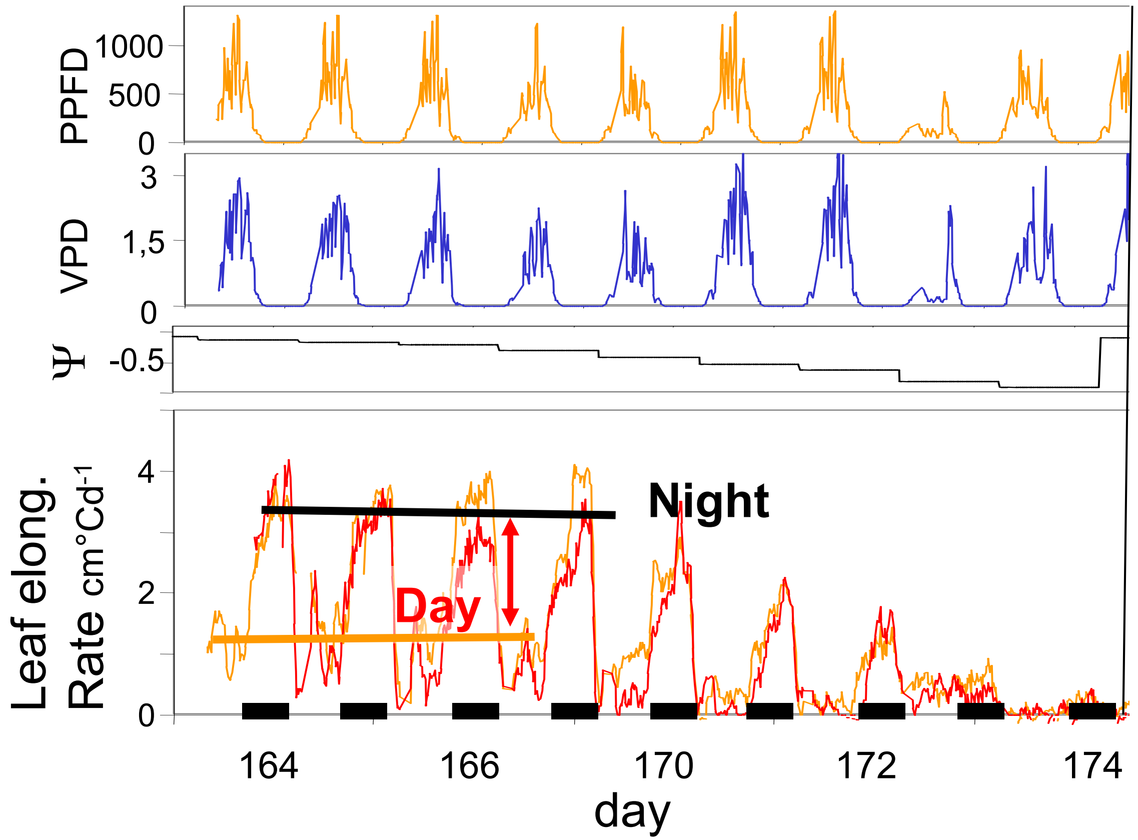
Leaf expansion in Maize under drought conditions

- Instantaneous response of leaf expansion to an environmental stress

- Under water deficit, the LER time course is accounted by 2 major stress :

. evaporative demand (VPD)
only during day time

$$LER = (T-T_0)\,(a - bVPD_{fac})$$



Leaf elongation rate for a 10-d period

Leaf expansion in Maize under drought conditions

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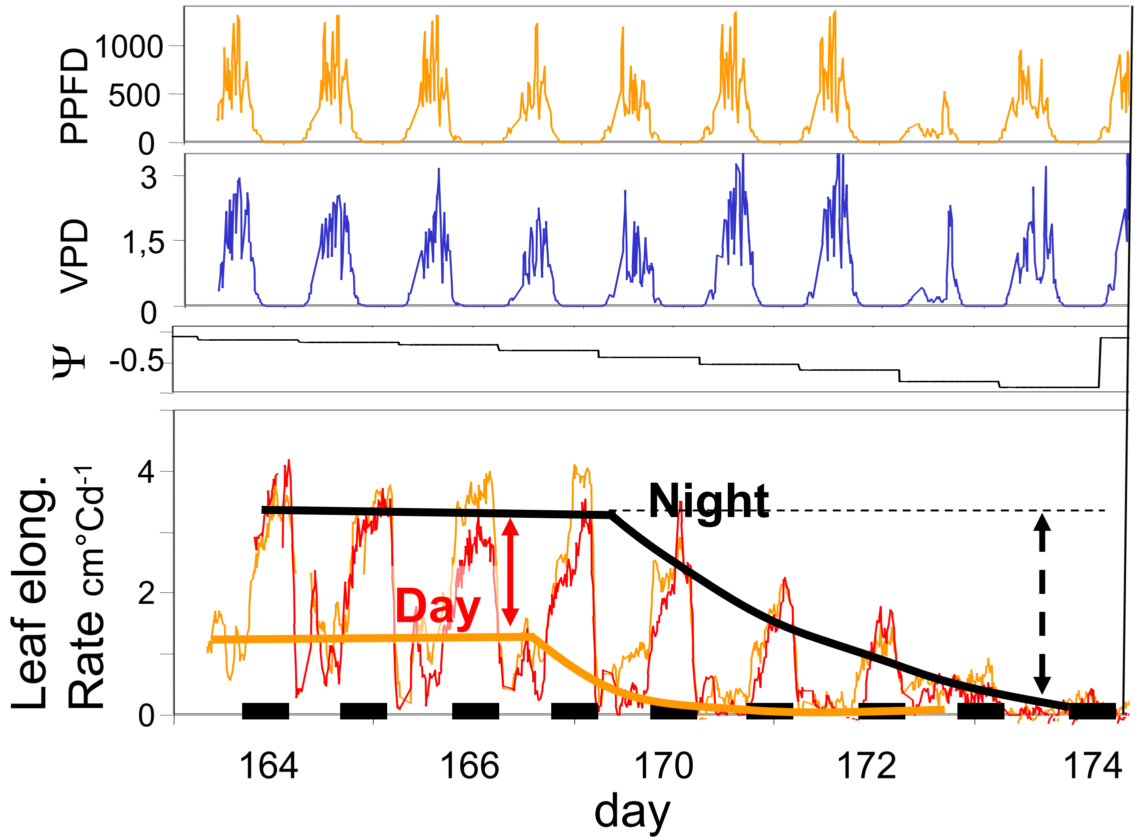
. **leaf predawn potential (ψ)**
Decline of night values

$$LER = (T-T_0)\ (a - c\ \Psi)$$

Time course modelled by the sum

$$LER = (T-T_0)\ (a - bVPD_{fa} - c\ \Psi)$$



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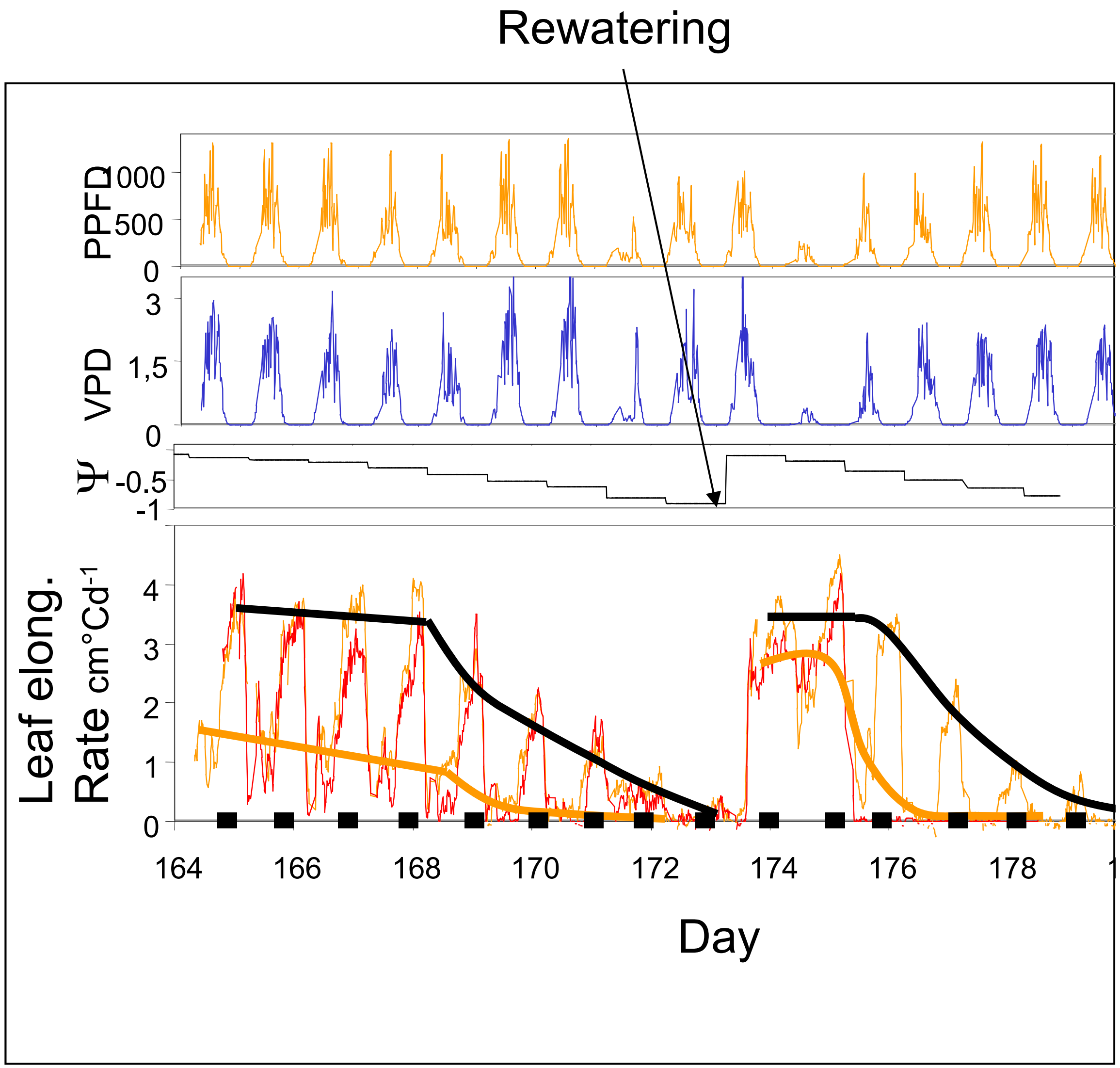
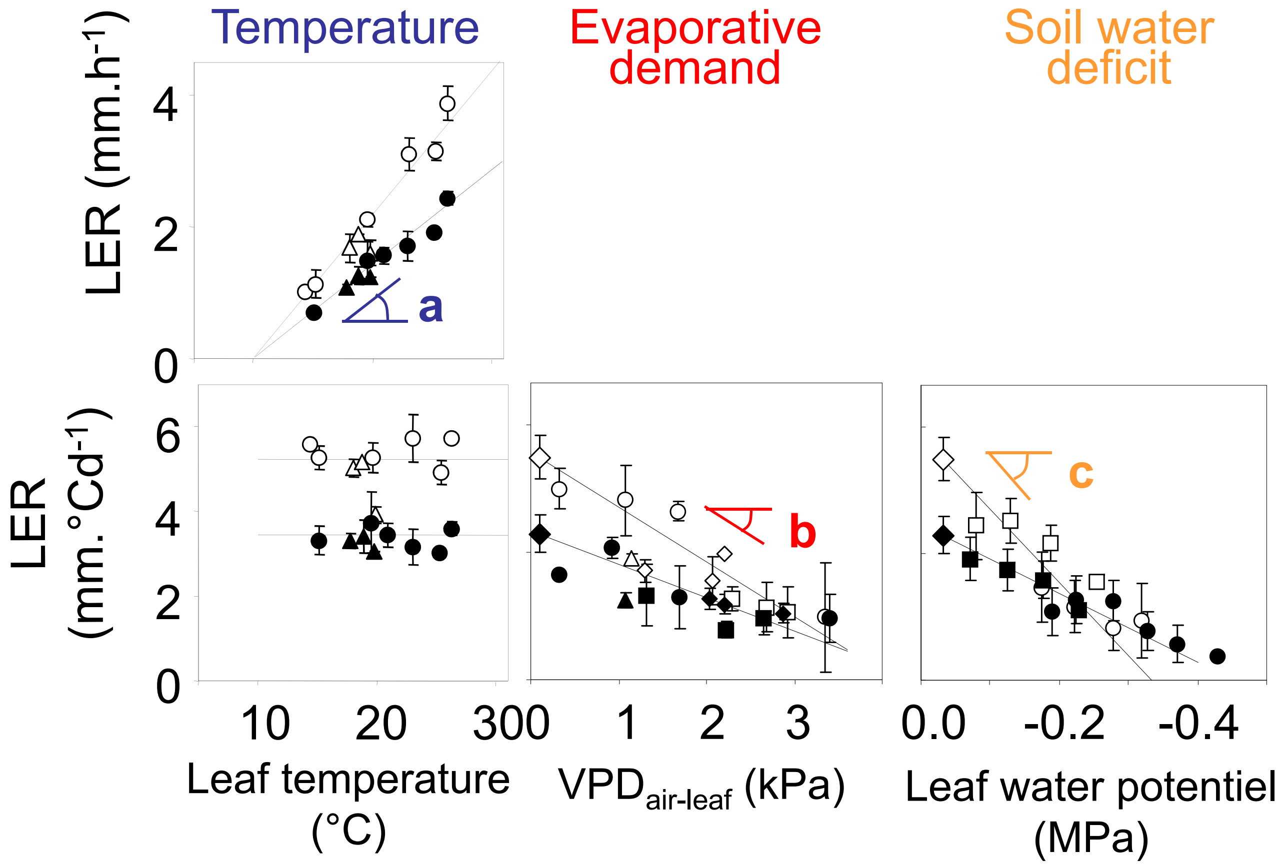


Leaf expansion in Maize under drought conditions
Response to temperature and soil and air water deficits

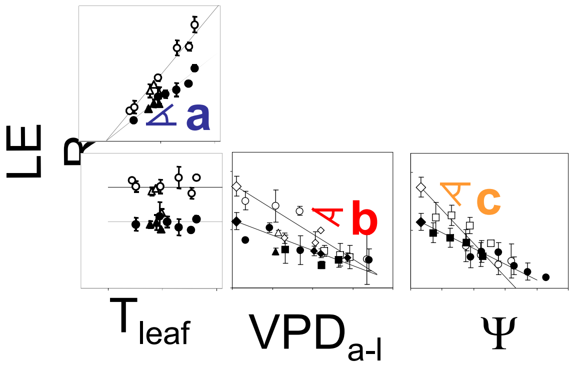


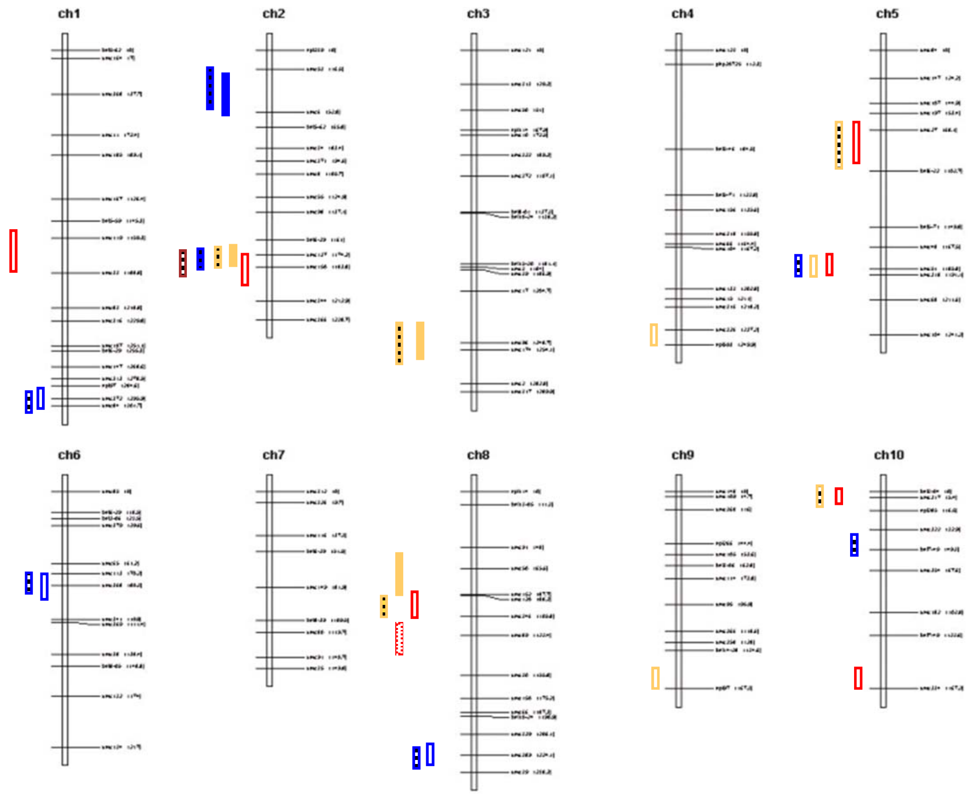
$$LER = dl/dt = (T - T_0)(a + b\ VPD_{air\text{-}leaf} + c\ \Psi)$$

1 genotype → 1 set of parameters of response curves (parameter 'indep.' of env.)

Reymond et al. 2003 Plant Phy

Leaf expansion in Maize under drought conditions
QTL related to env. responses





Welcker et al. 2007

$$LER = dl/dt = (T-T_0)(a + b\, VPD_{air\text{-}leaf} + c\, \Psi)$$

$$a = \bar{a} + \Sigma\, \alpha\, QTL$$

$$c = \bar{c} + \Sigma\, \gamma\, QTL$$

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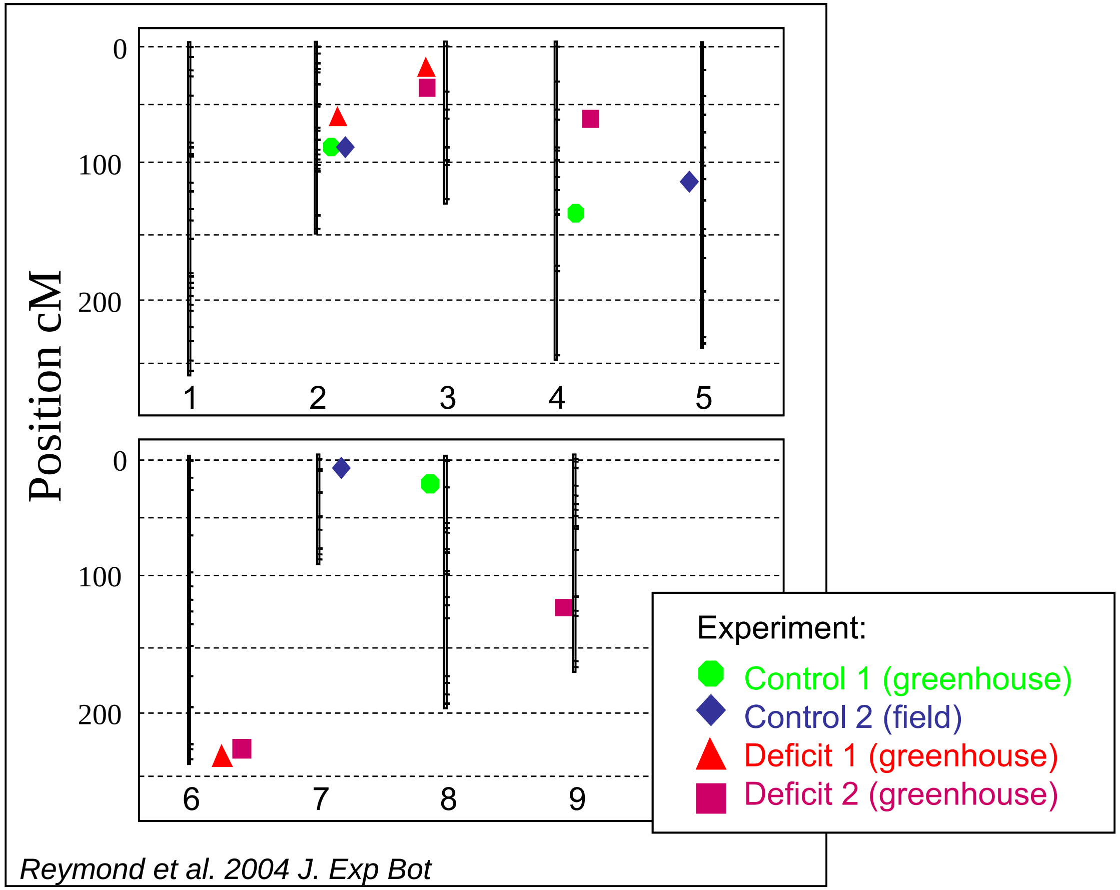
Leaf expansion in maize under drought conditions
QTL related to environment responses

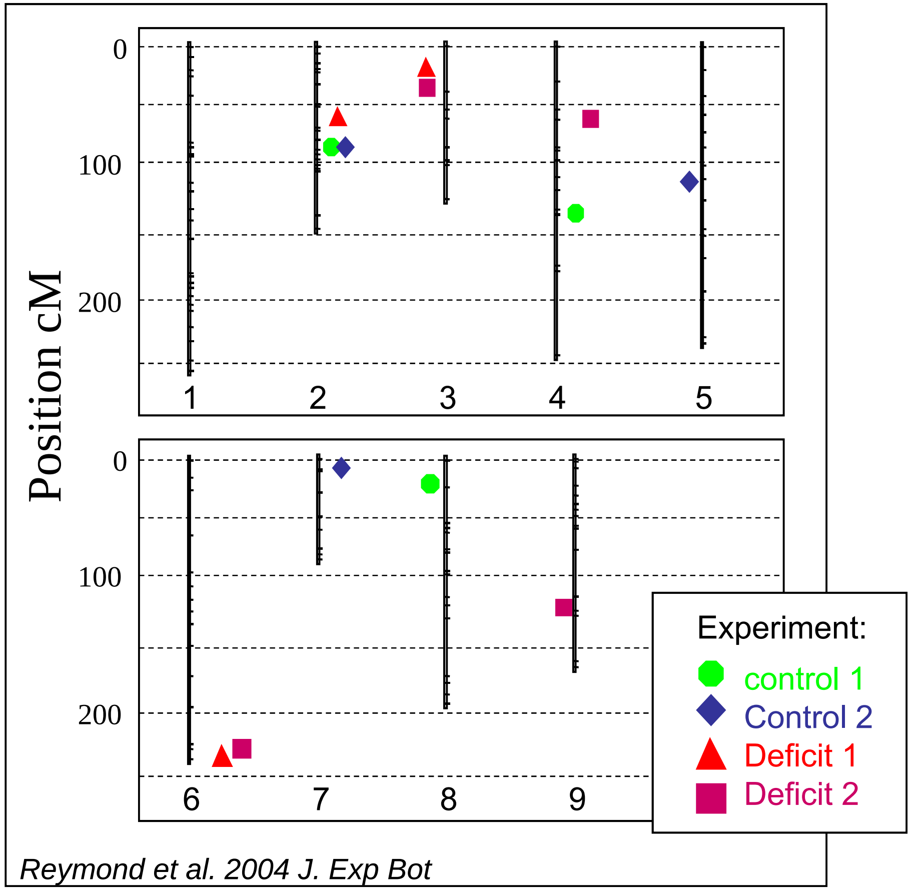
QTLs of leaf length



QTLs of leaf length were not stable among experiments

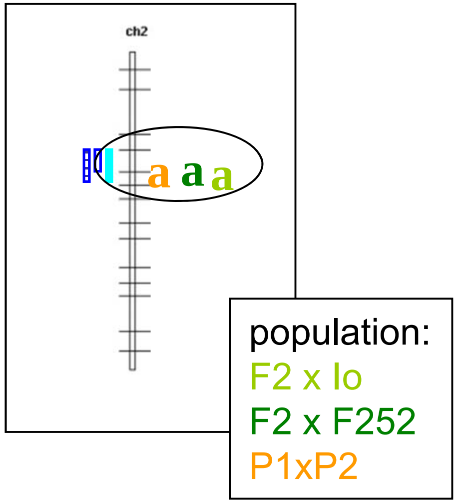
Leaf expansion in maize under drought conditions QTL related to environment responses

QTLs of leaf length



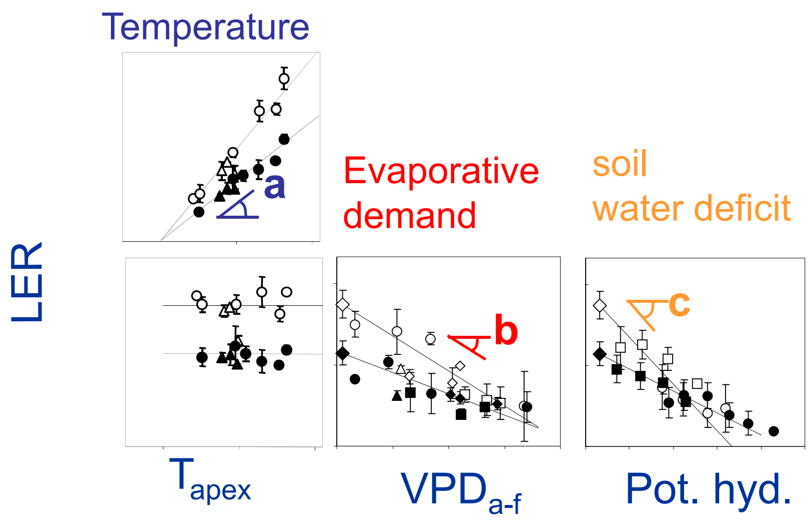
QTLs of leaf length were not stable among experiments

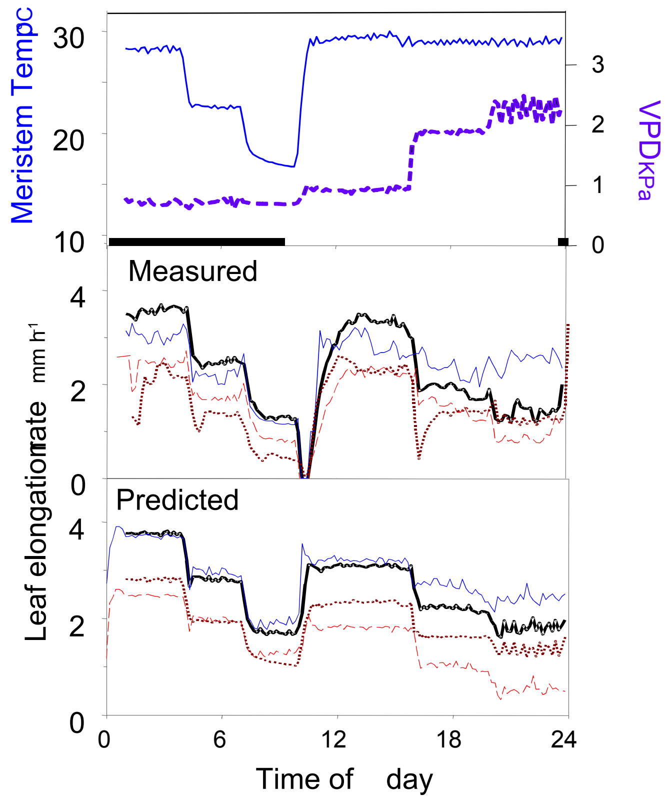
QTLs of maximum elongation rate (response to temperature)



A QTL co-location for slope *a* in three populations

Modelling the effects of the genetic variability – Example: Leaf expansion rate in maize





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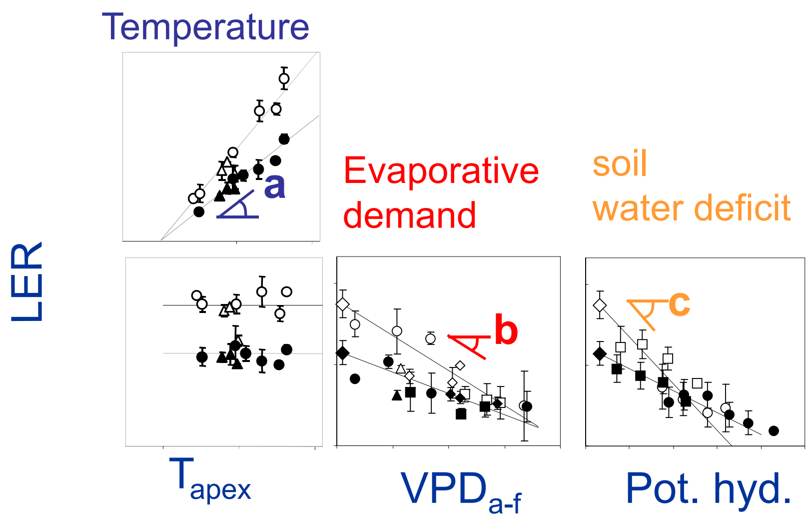
Reymond et al. 2003 *Plant Physiology* **131**:664-675.

Modelling the effects of the genetic variability – Example: Leaf expansion rate in maize



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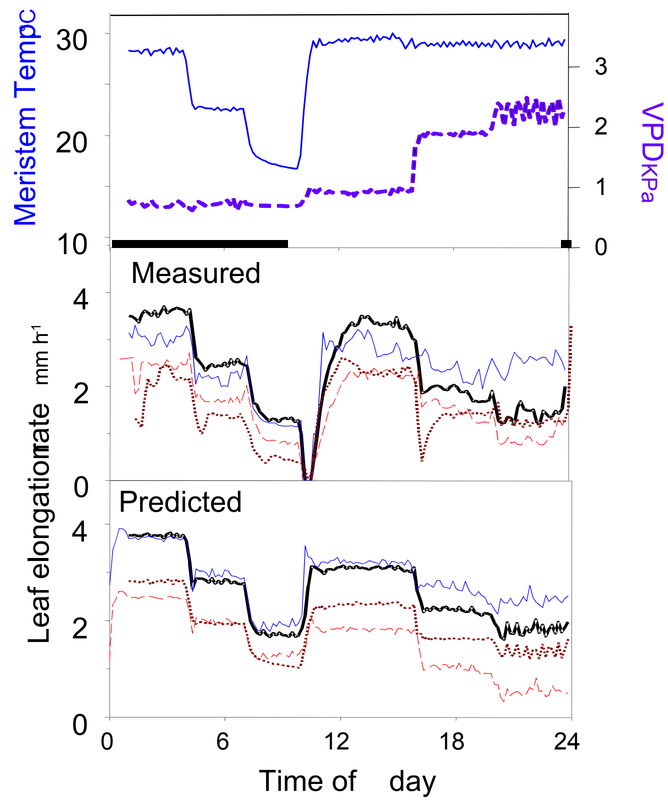
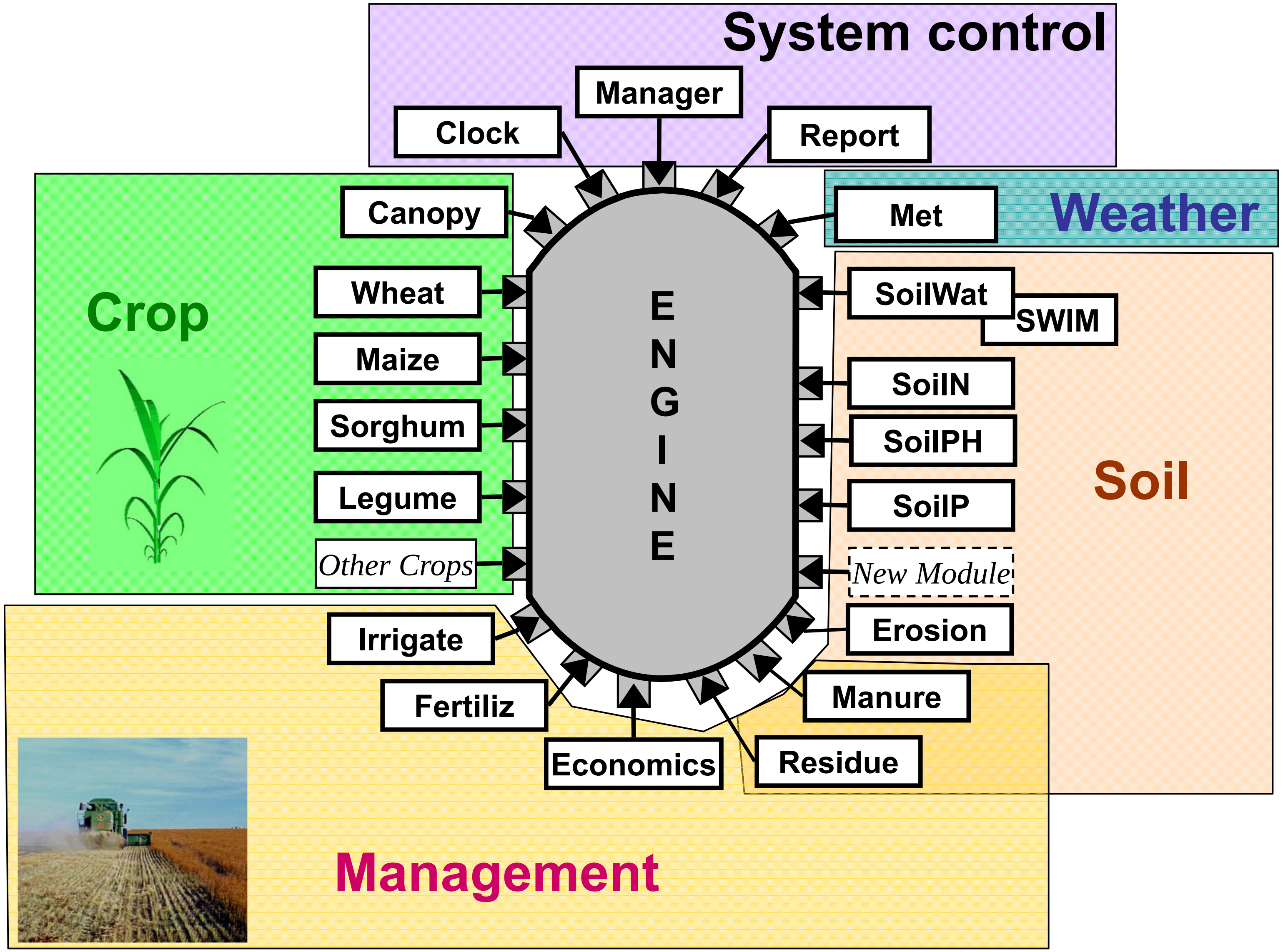


1 genotype → 1 set of parameters of response curves (parameter 'indep.' of env.)

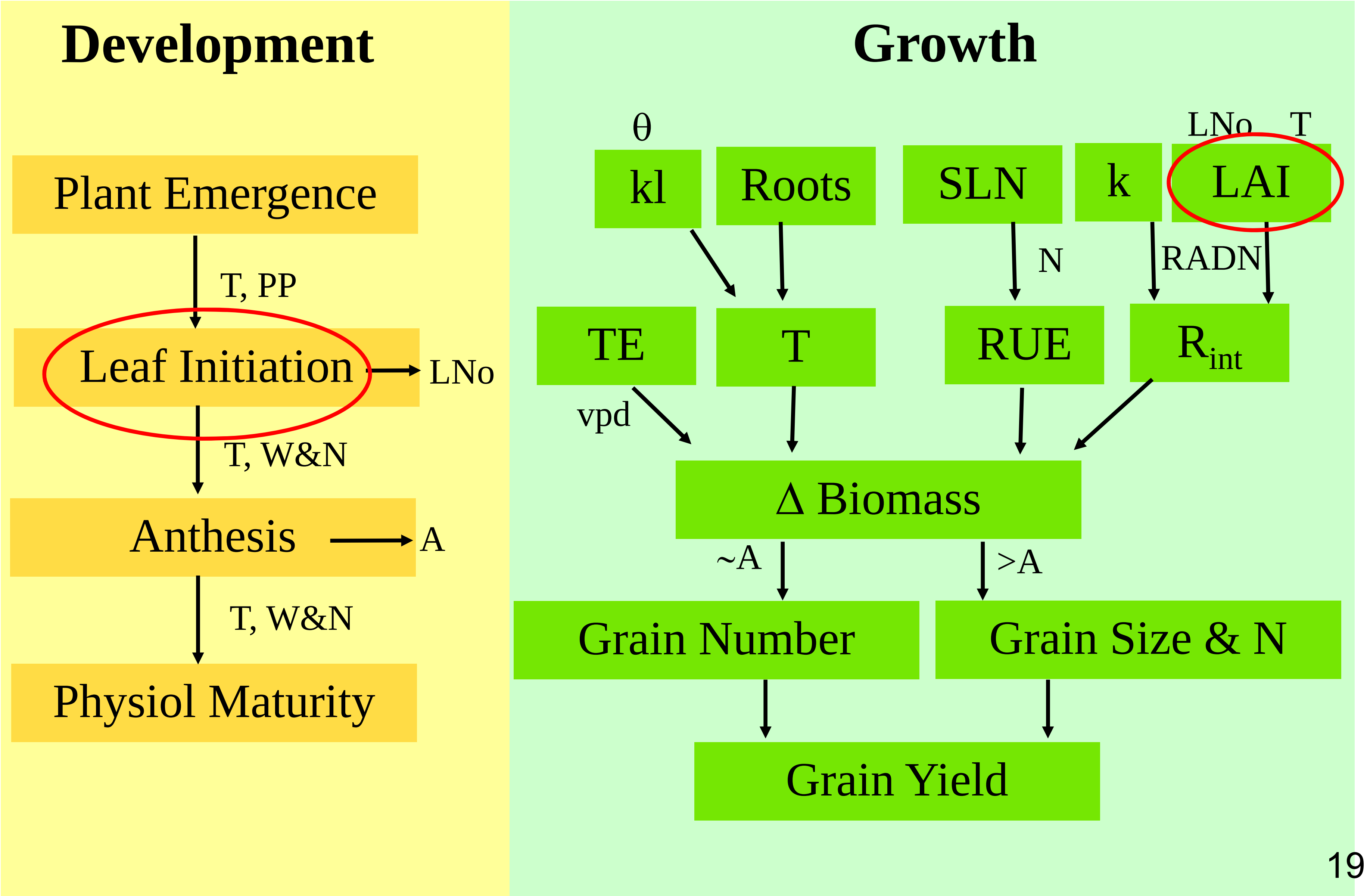
Reymond et al. 2003 *Plant Physiology* **131**:664-675.

APSIM (Agricultural Production Systems Simulator)

A modular crop model

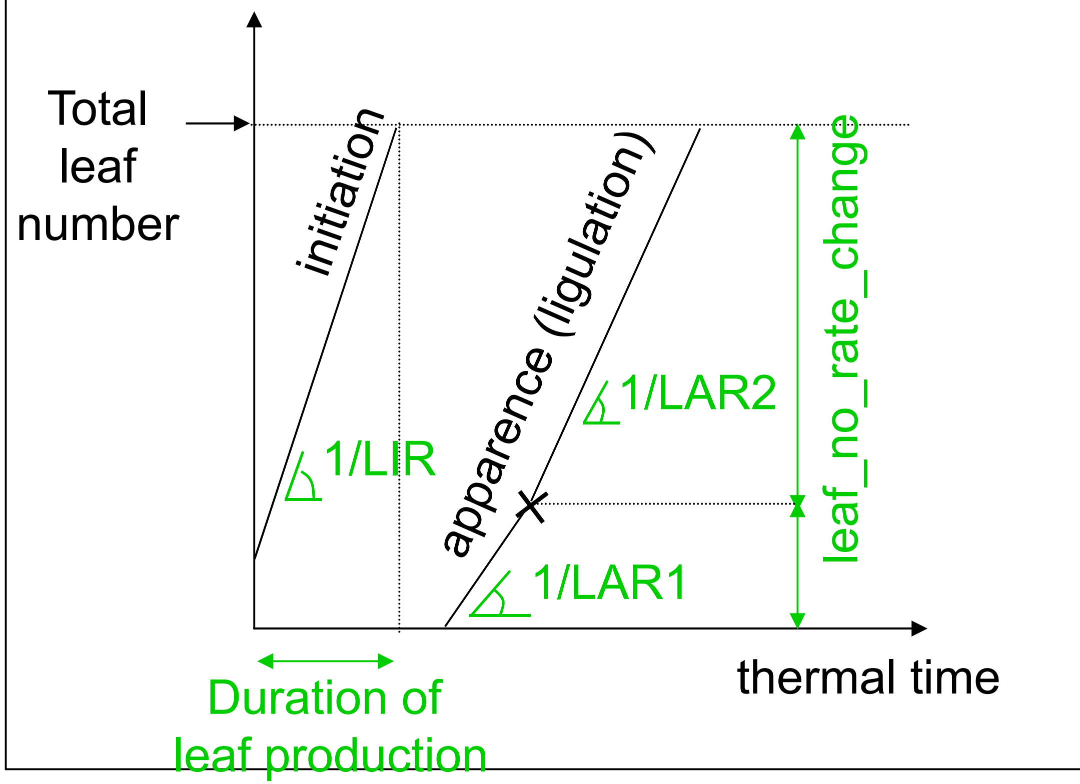


A general cropping system simulation for plant development

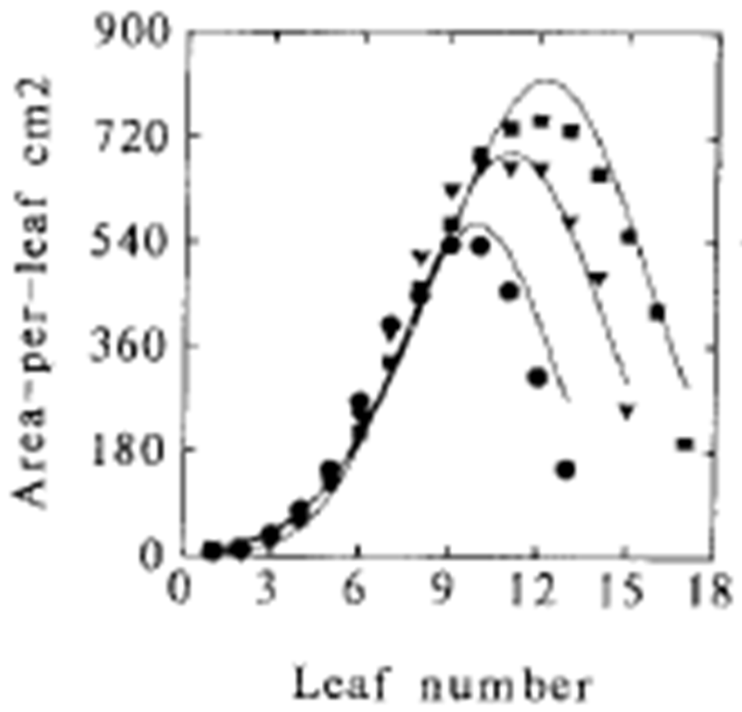


Leaf development in APSIM

Leaf development

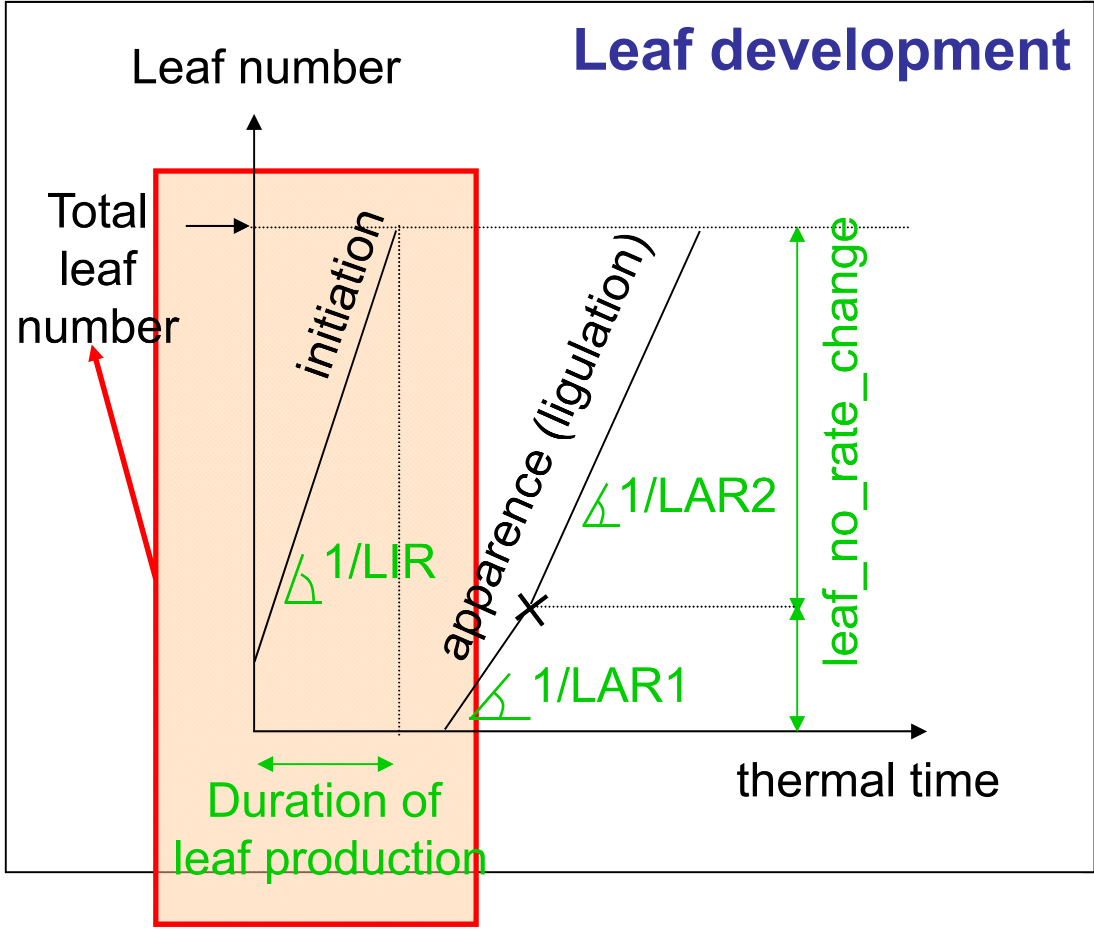


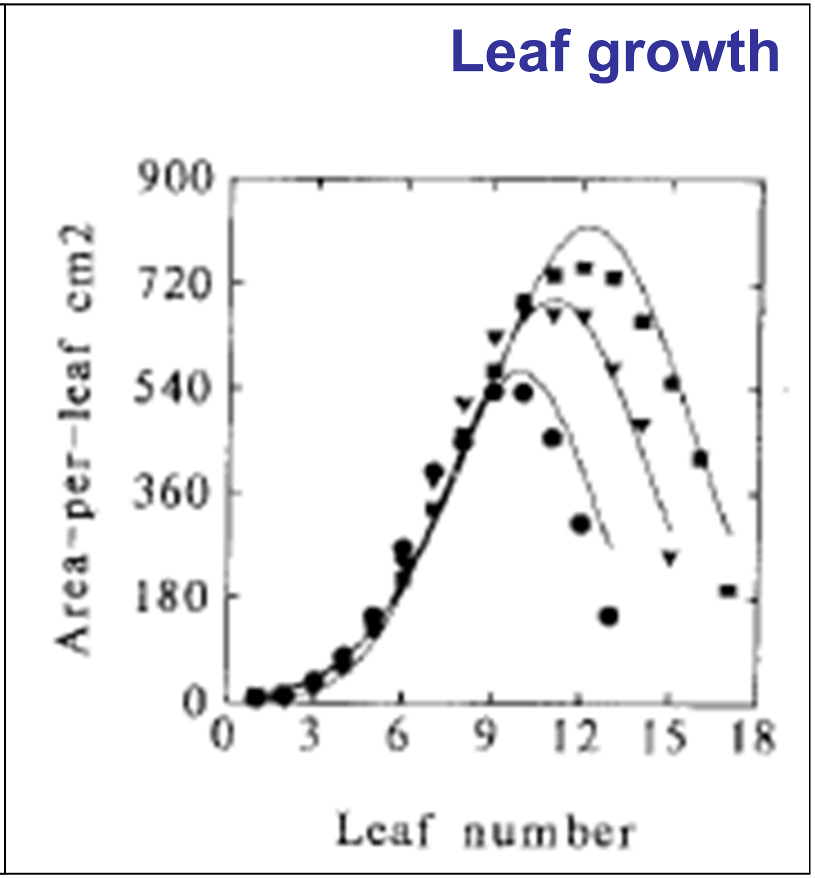
Leaf growth



Keating & Wafula 92

Leaf development in APSIM

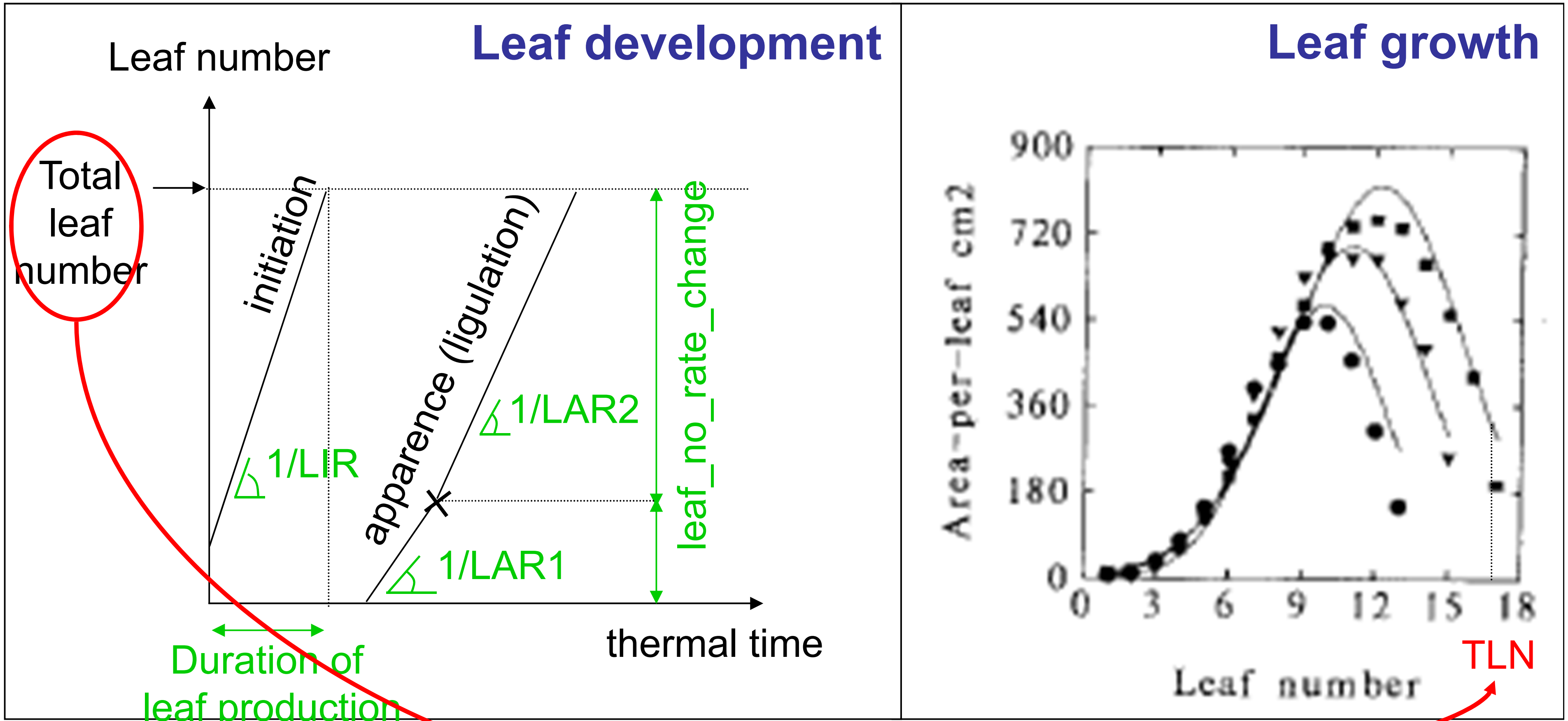




Keating & Wafula 92

Leaf initiation rate & duration → total leaf number

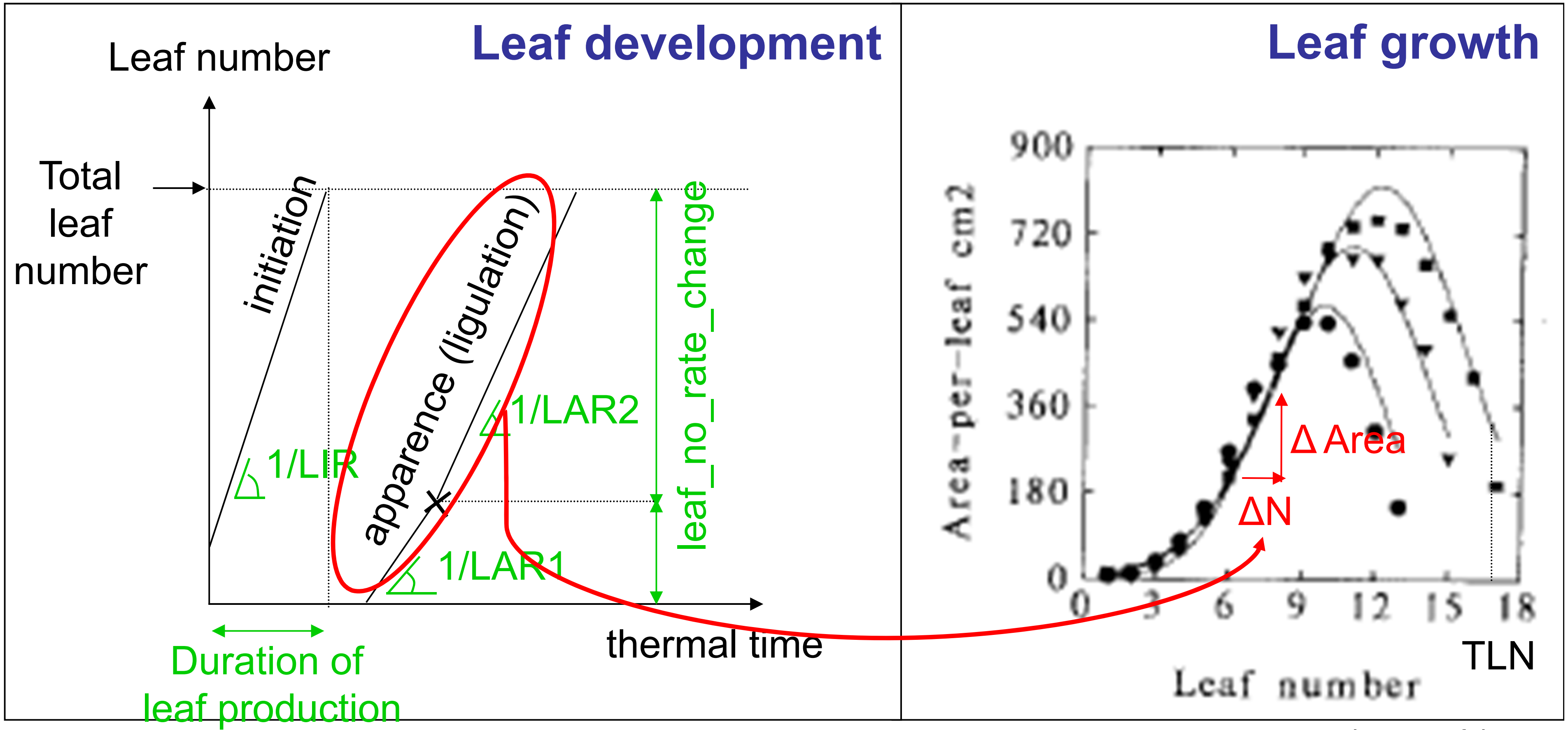
Leaf development in APSIM



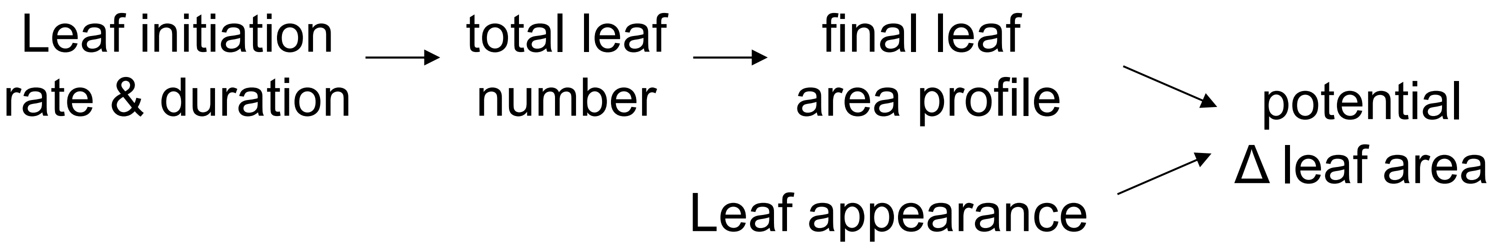
Keating & Wafula 92

Leaf initiation rate & duration → total leaf number → final leaf area profile

Leaf development in APSIM



Keating & Wafula 92



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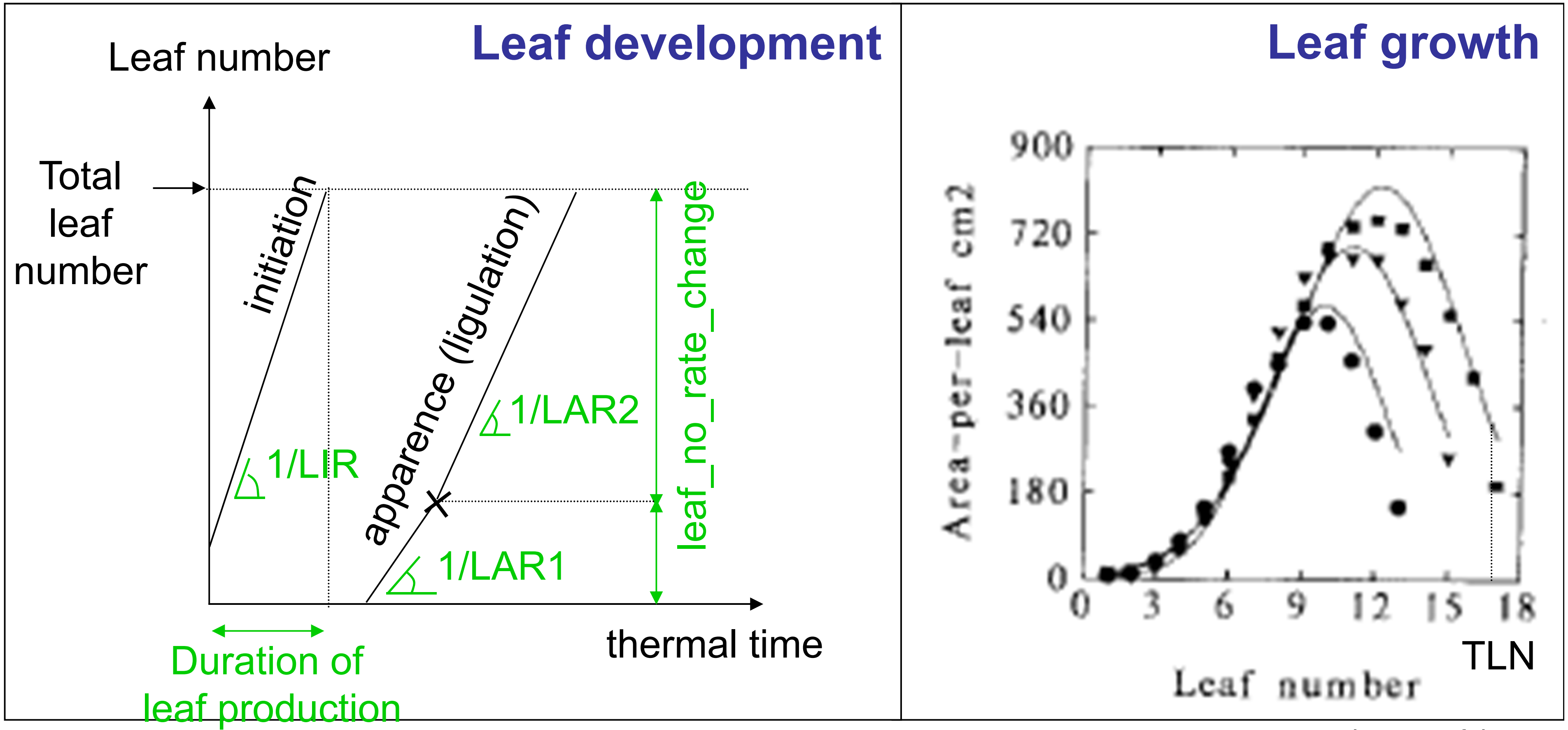


Keating & Wafula 92

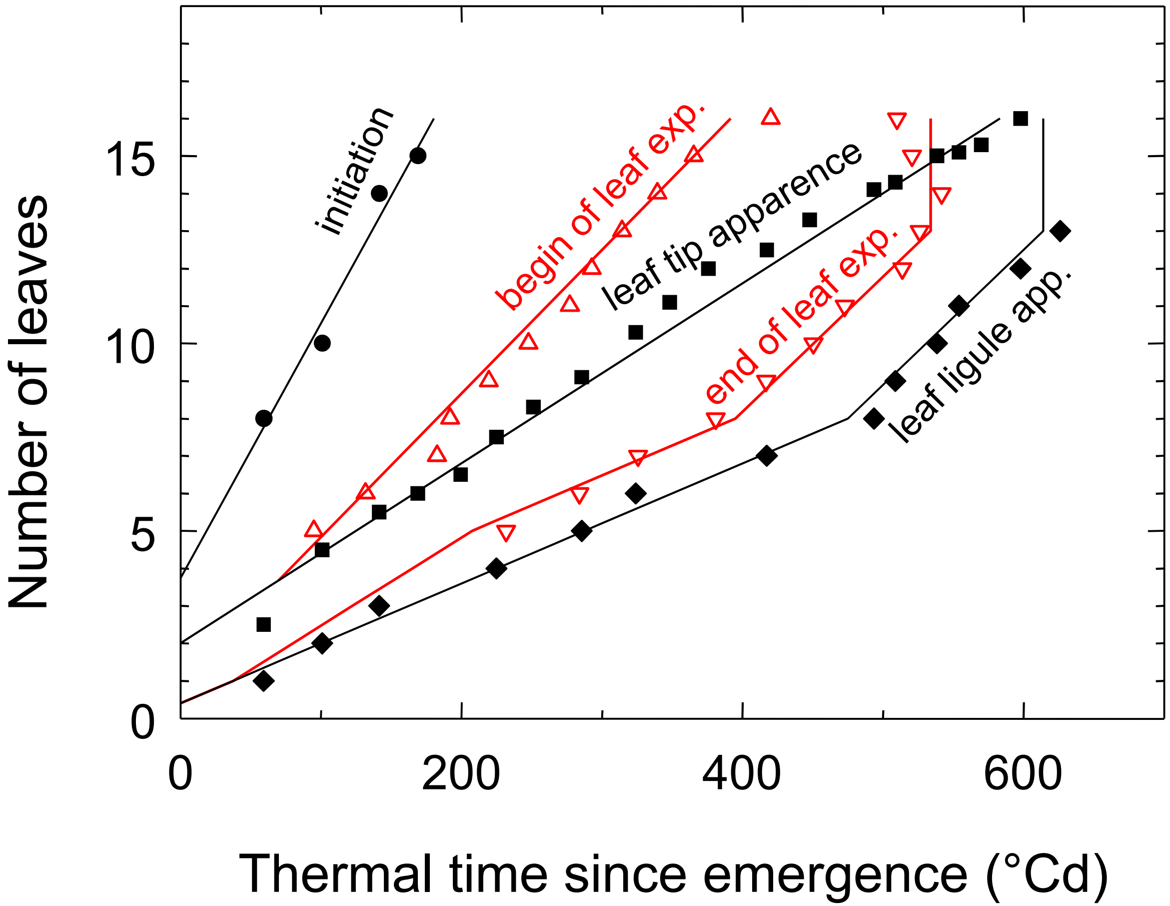
Leaf initiation rate & duration → total leaf number → final leaf area profil

Leaf appearance

final leaf area profil + Leaf appearance → potential Δ leaf area → effective Δ leaf area

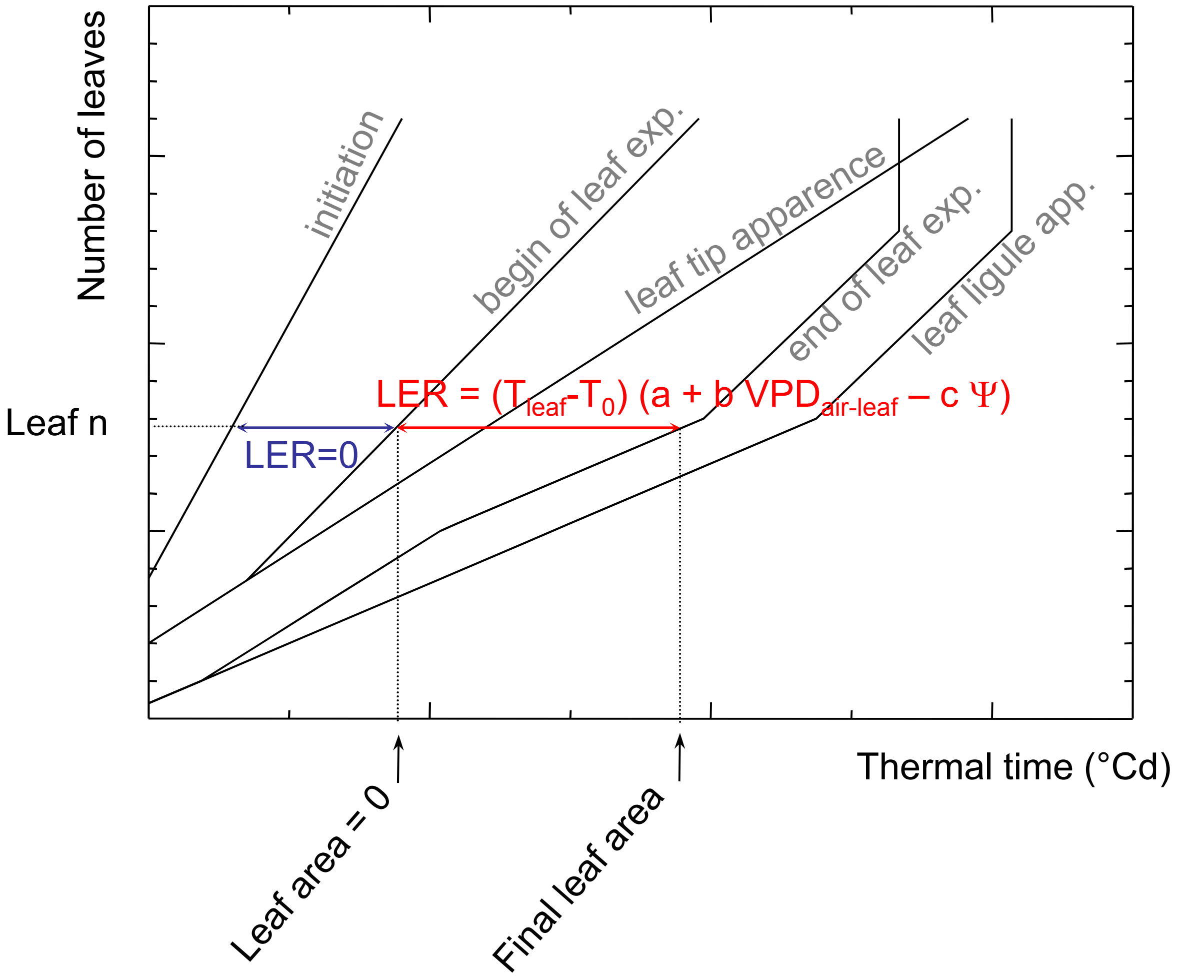
water supply / demand → effective Δ leaf area

New APSIM module for leaf development



Chenu et al (2008) PCE 31:378-391.

New APSIM module for leaf development



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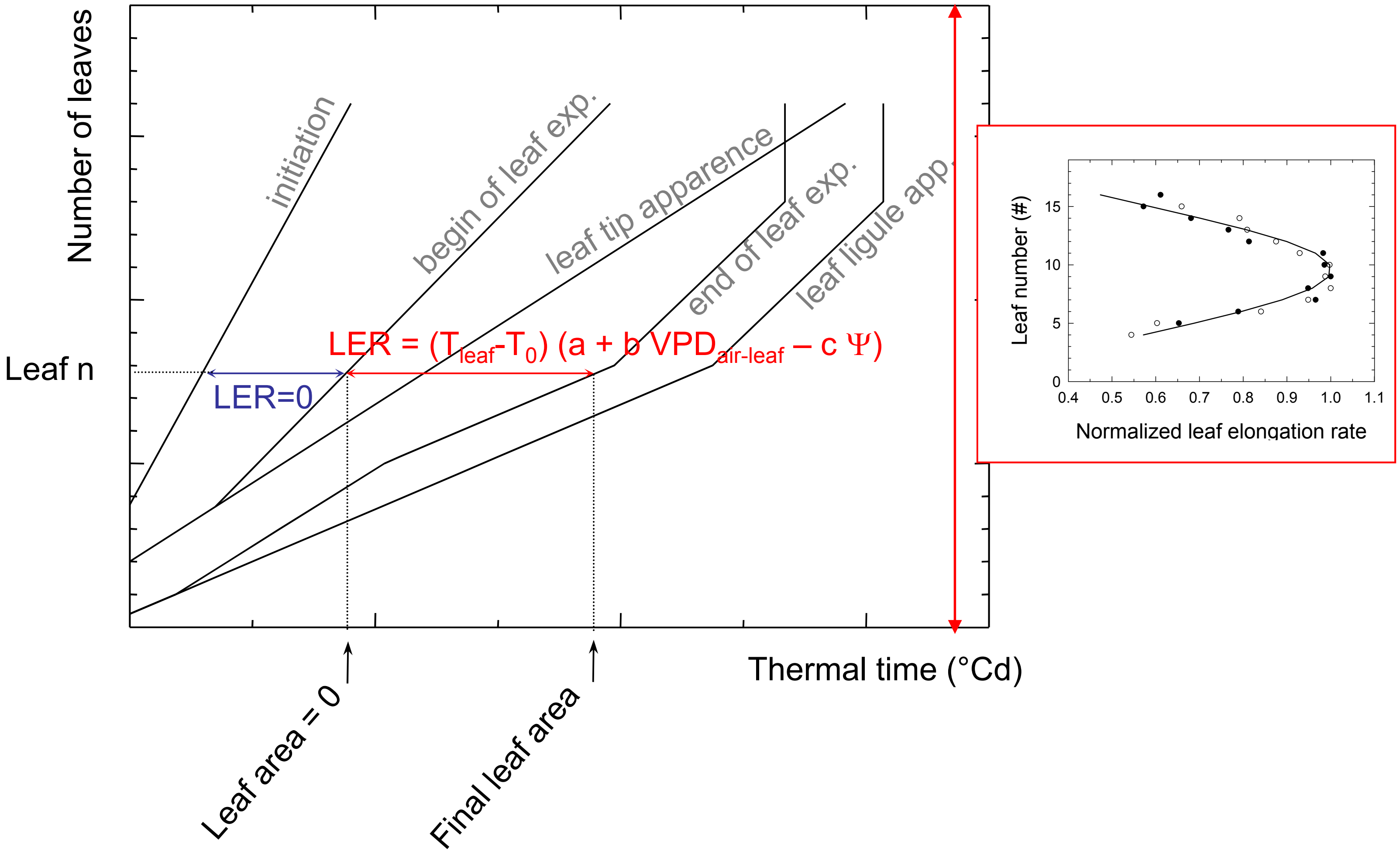

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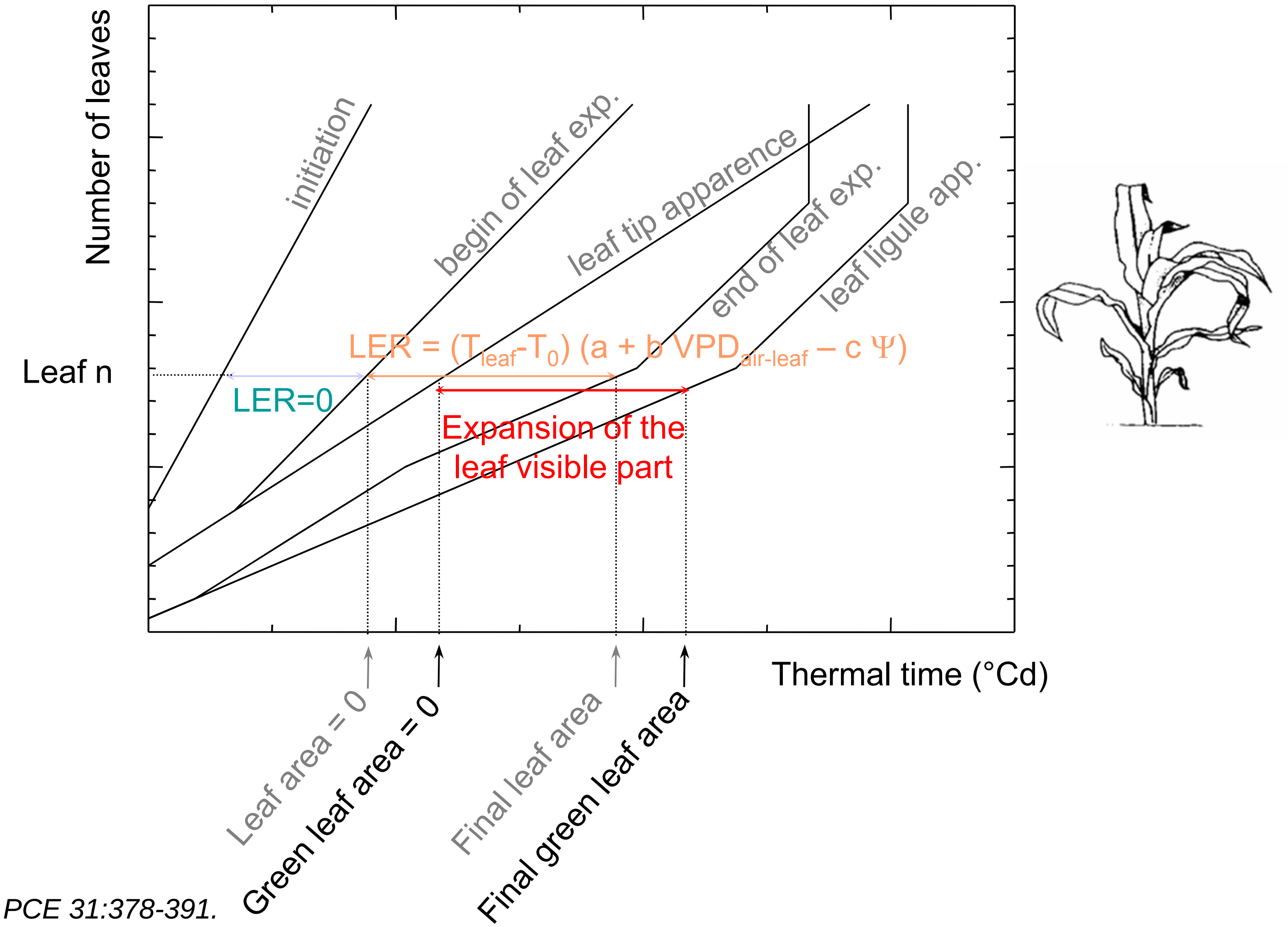

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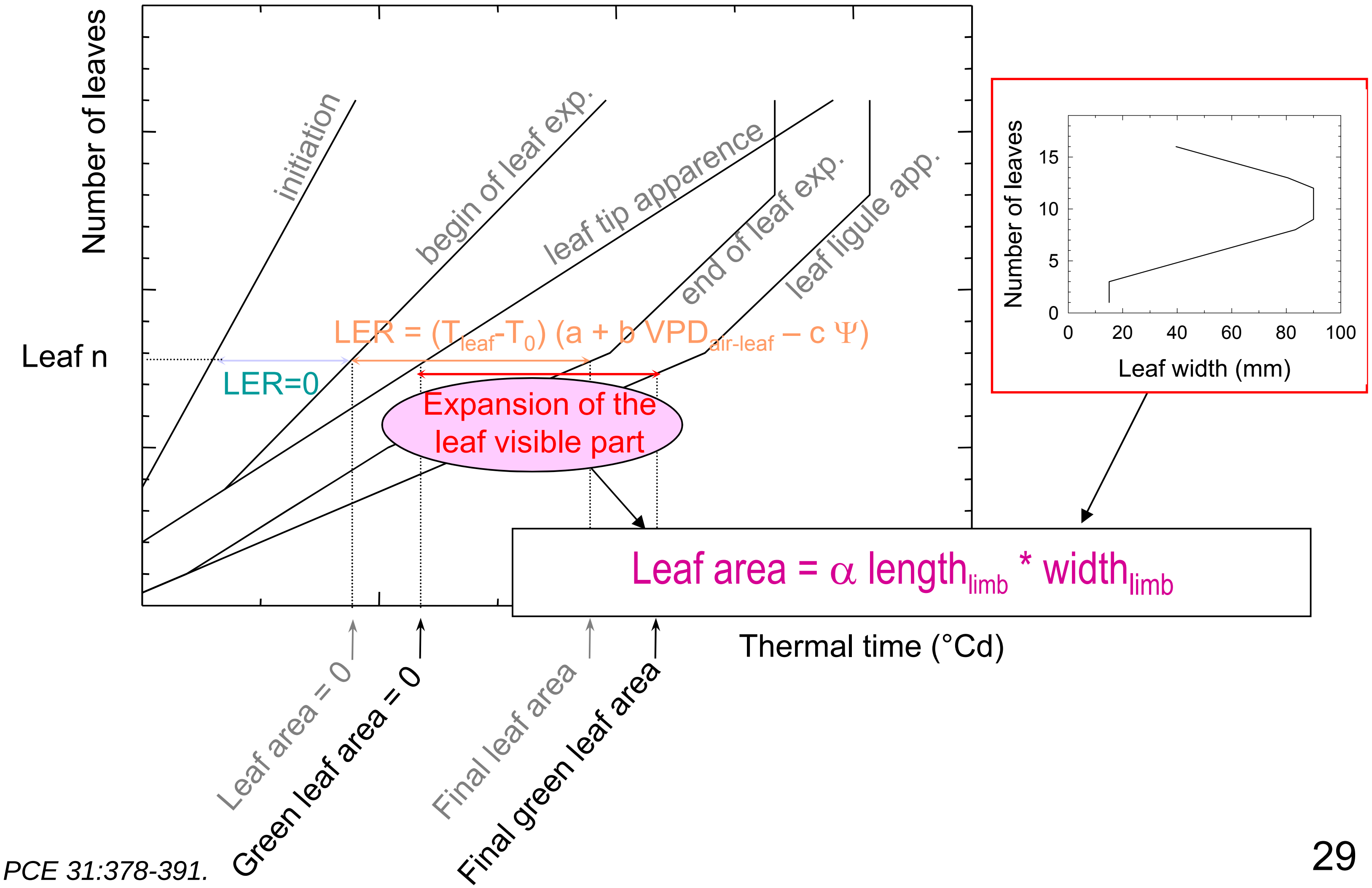
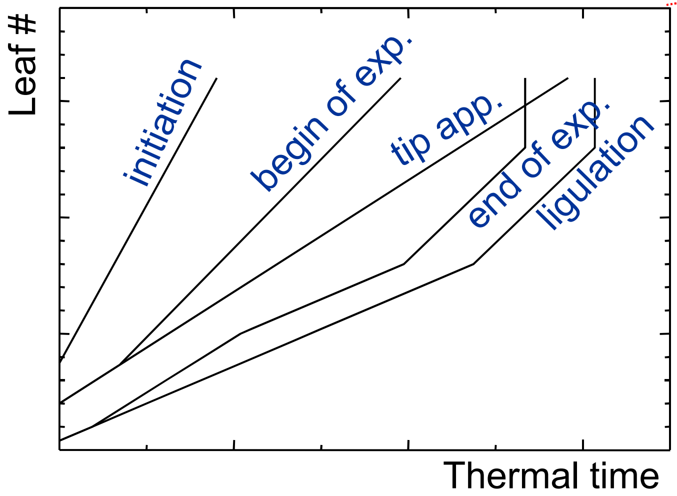
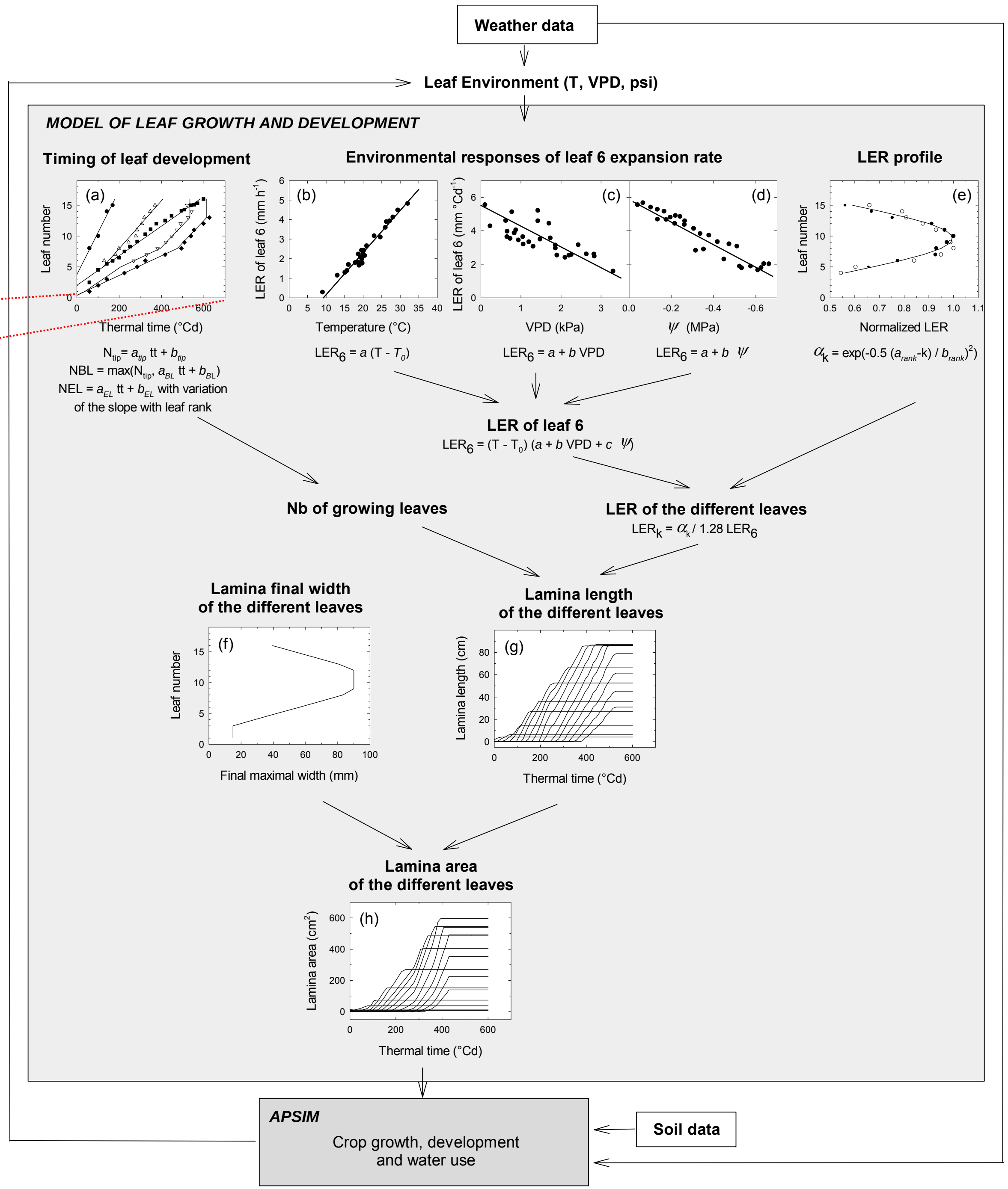


Chenu et al (2008) PCE 31:378-391.

Integrating QTL information on leaf growth response into APSIM





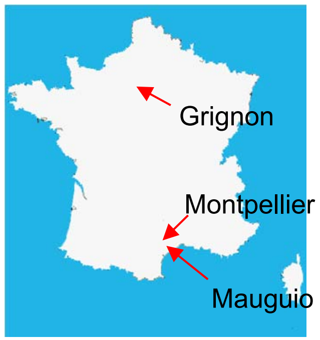
Generates leaf size

Chenu et al (2008) PCE 31:378-391.

Test of the model

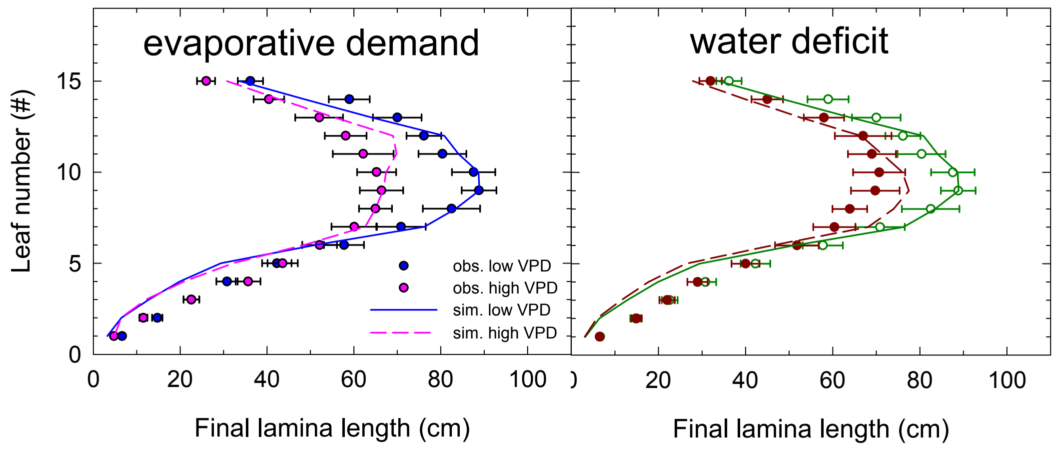
Exp.	Location	Sowing date	Treatment	Radiation	Rain	Temperature	$VPD_{air-meristem}$
				($MJ\ m^{-2}$)	(mm)	(°C)	(kPa)
GR92ap	Grignon, North of France	April 27,1992	control	21.1	62	15.6	1.098
GR92ap	Grignon, North of France	April 27,1992	water deficit	21.1	0	15.6	1.111
MP94jl	Montpellier, South of France	July 19, 1994	control	20.7	30	24.8	2.551
MP94jl	Montpellier, South of France	July 19, 1994	water deficit	20.7	30	24.8	2.66
MP95ma	Montpellier, South of France	May 16, 1995	control	22.7	39	20	1.49
MP95jn	Montpellier, South of France	June 20, 1995	control	23.9	13	24	1.95
MP95jn	Montpellier, South of France	June 20, 1995	water deficit	23.9	13	24	2.054
MP95jl	Montpellier, South of France	July 10, 1995	control	21.6	88	24.7	2.066
MP95jl	Montpellier, South of France	July 10, 1995	water deficit	21.6	88	24.7	2.086
MA97ma	Mauguio, South of France	May 14, 1997	control	19.1	151	19.5	1.359
MA97jn	Mauguio, South of France	June 18, 1997	control	21.3	65	22	1.596
MA98ma	Mauguio, South of France	May 20, 1998	control	23	47	21.1	1.7

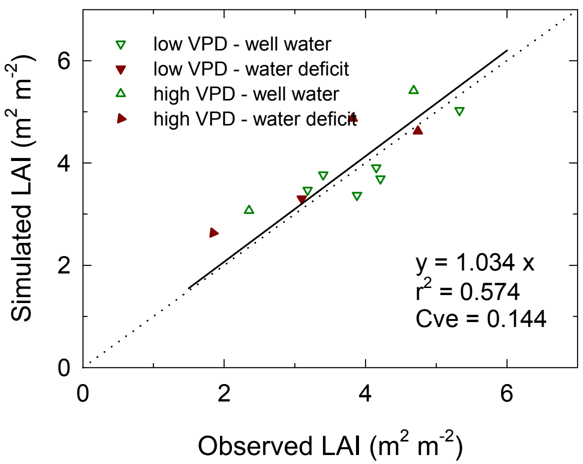
- 1 situation => Parametrisation of the model
- 11 situations => Test of the model



Chenu et al. PCE 2008

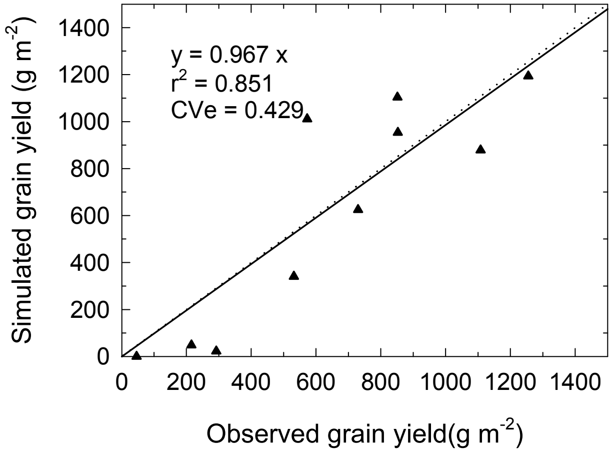
Test of the model





Accurate predictions
of leaf elongation, LAI and yield
in contrasting climatic and drought conditions
(12 field conditions)

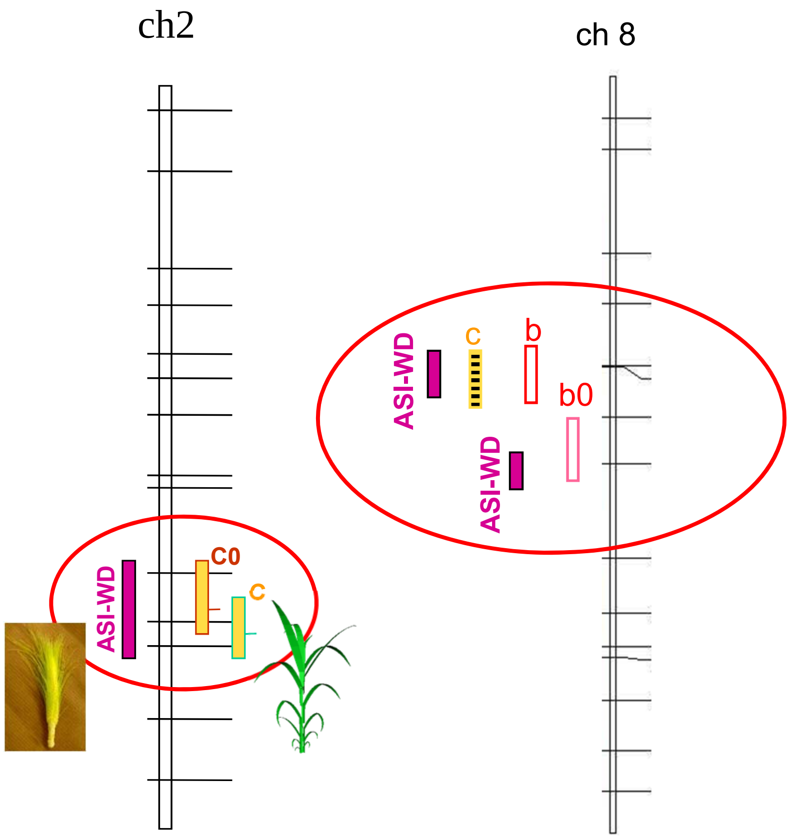
=> Capacity to simulate G x E
for leaf area & yield
=> G-to-P prediction



Chenu et al. PCE 2008

Reproductive development

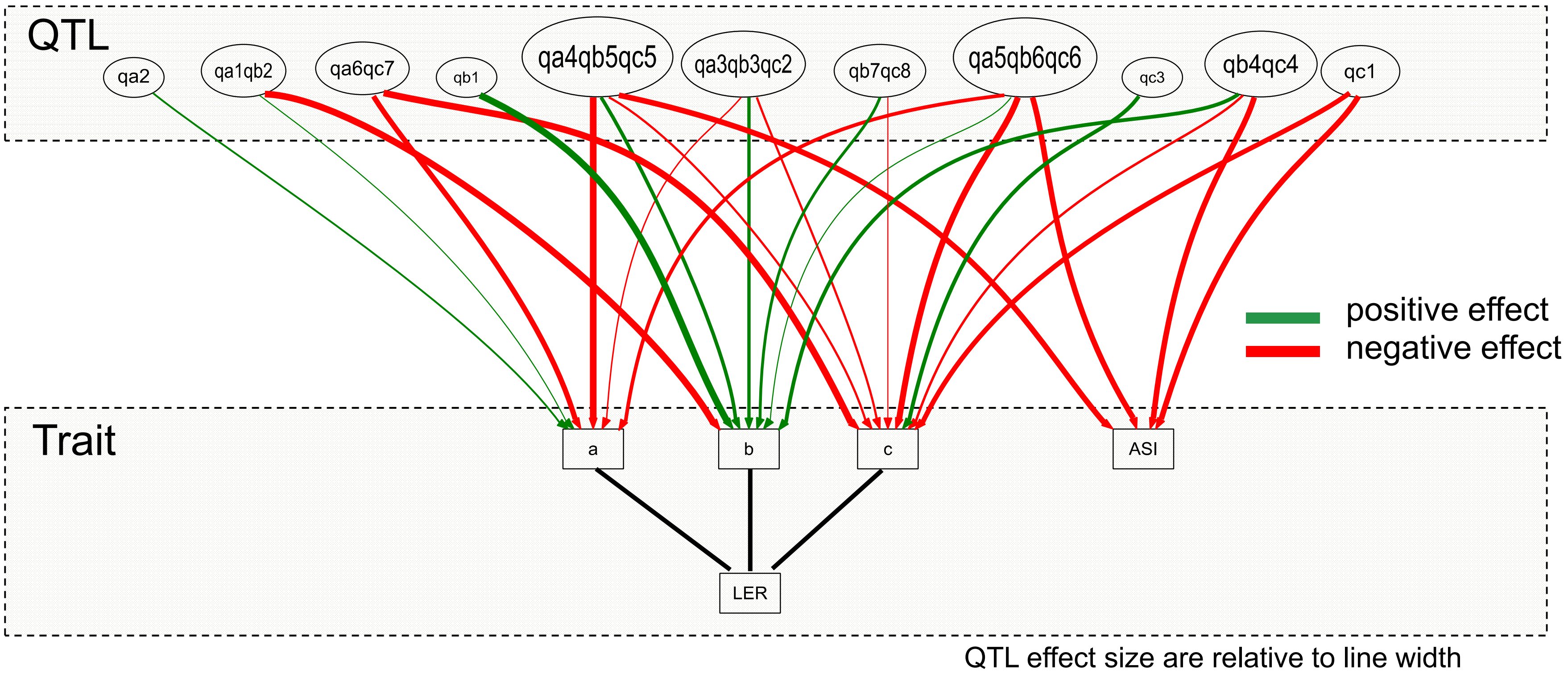
- Common QTLs for ASI and the response of leaf elongation under water deficit



⇨ Effect of the QTLs of ASI integrated in APSIM.

Welcker et al. 2007

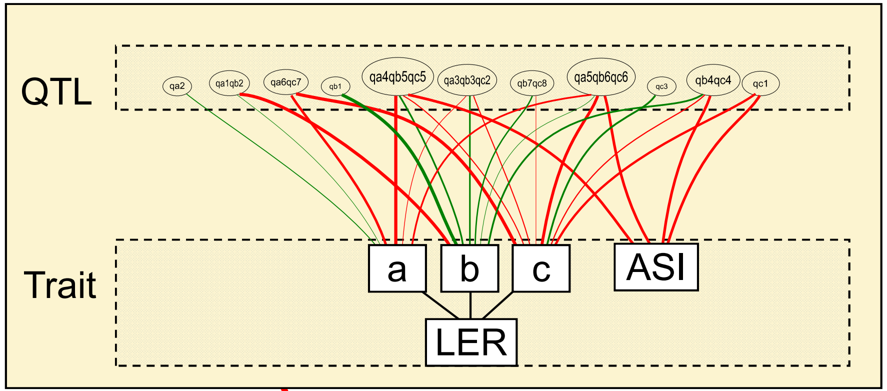
QTL network for leaf and silk elongation



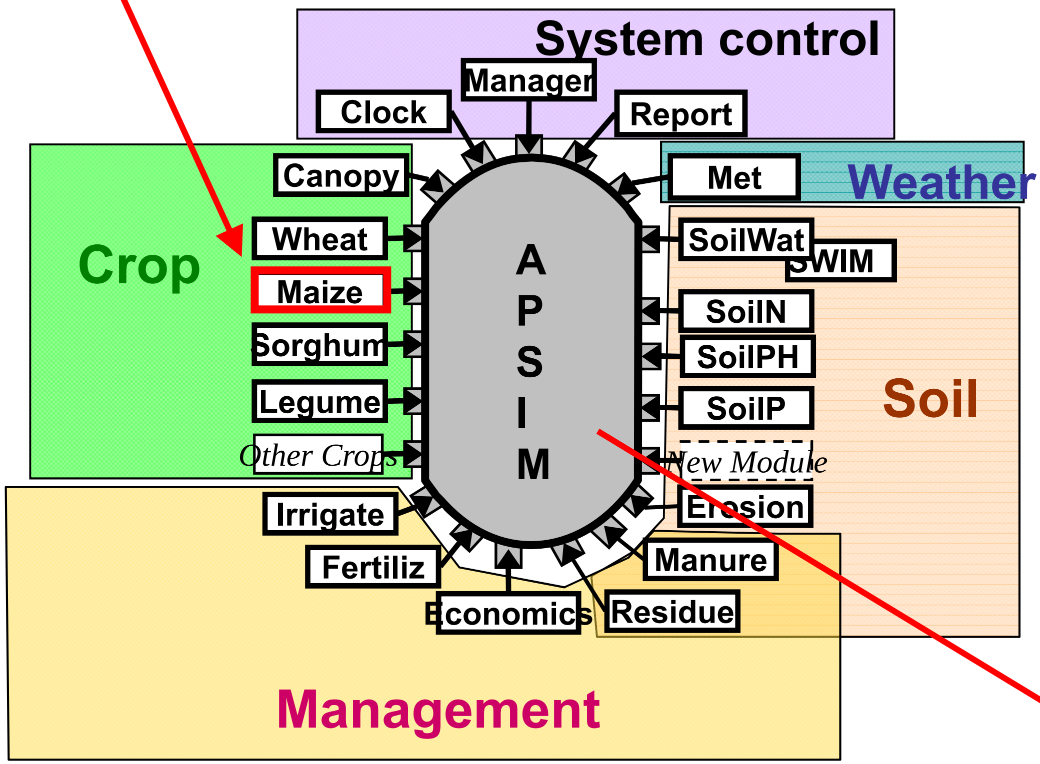
Complex interactions between the QTL for a, b, c and ASI

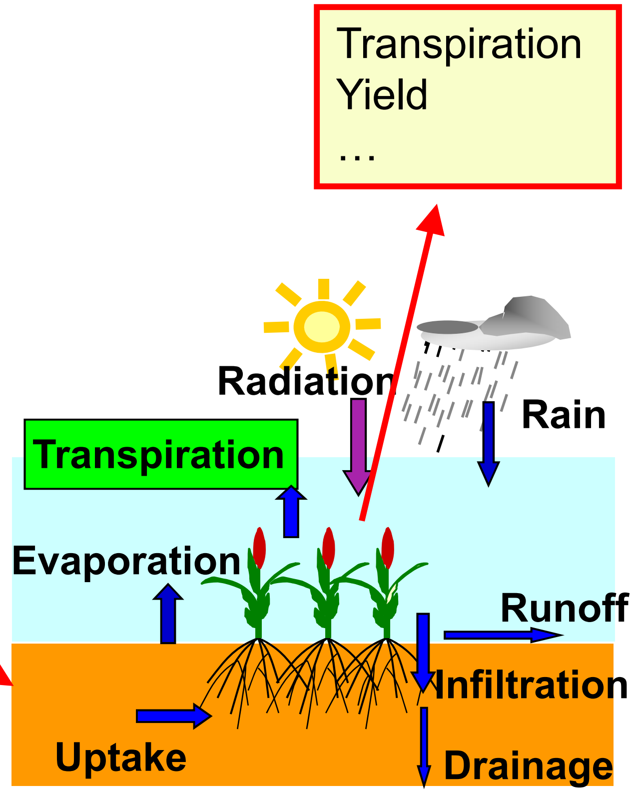
Welcker et al. J. Exp. Bot. 2007

QTL network



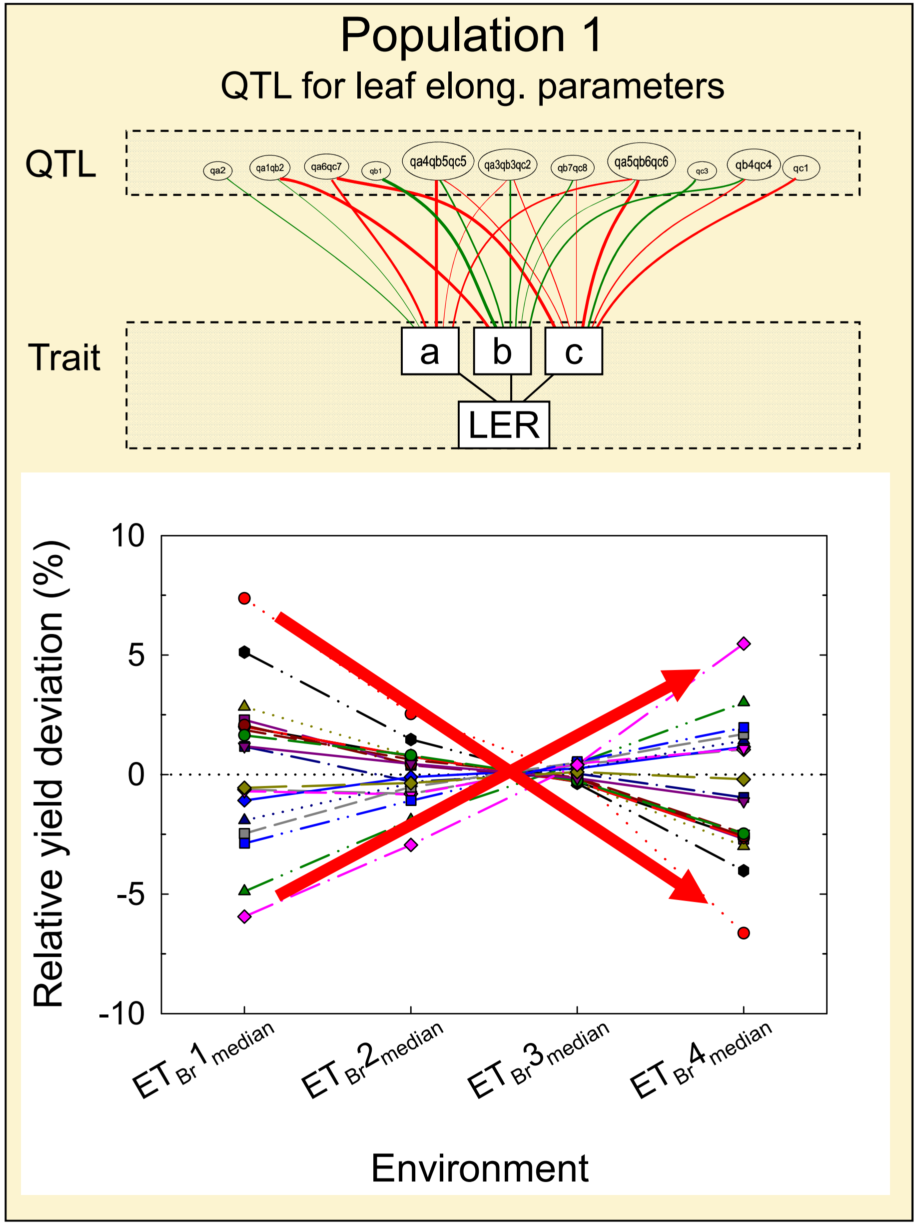
Welcker et al. J. Exp. Bot. 2007



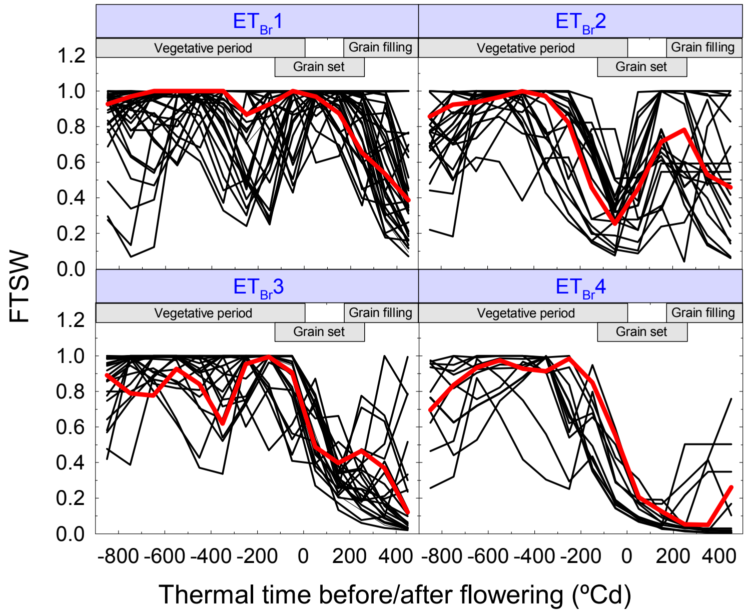


Chenu et al (2008) PCE 31:378-391.
Chenu et al (2009) Genetics 183:1507-1523.

Evaluation of the effect on yield in Sete Lagoas - Brazil



- Cross-over interactions for yield
- Genetic variability simulated highly varies across env.

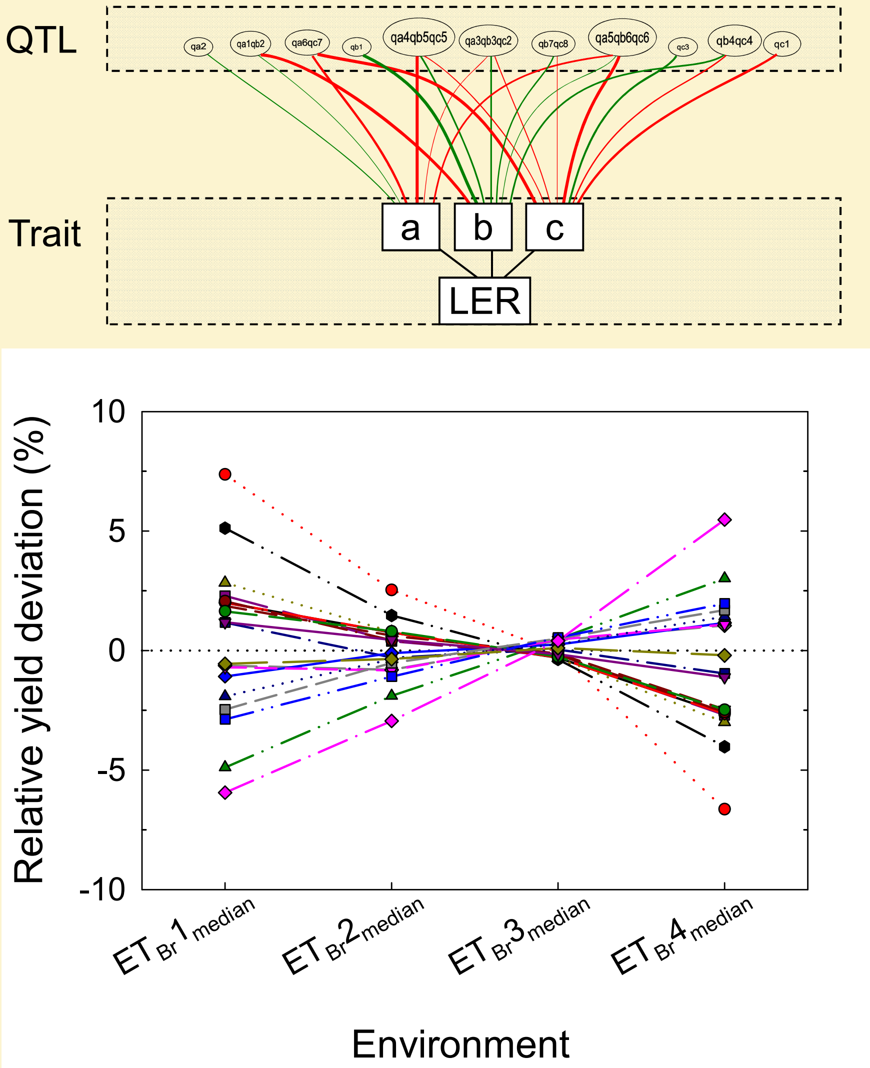


Chenu et al. Genetics 2009

Evaluation of the effect on yield in Sete Lagoas - Brazil

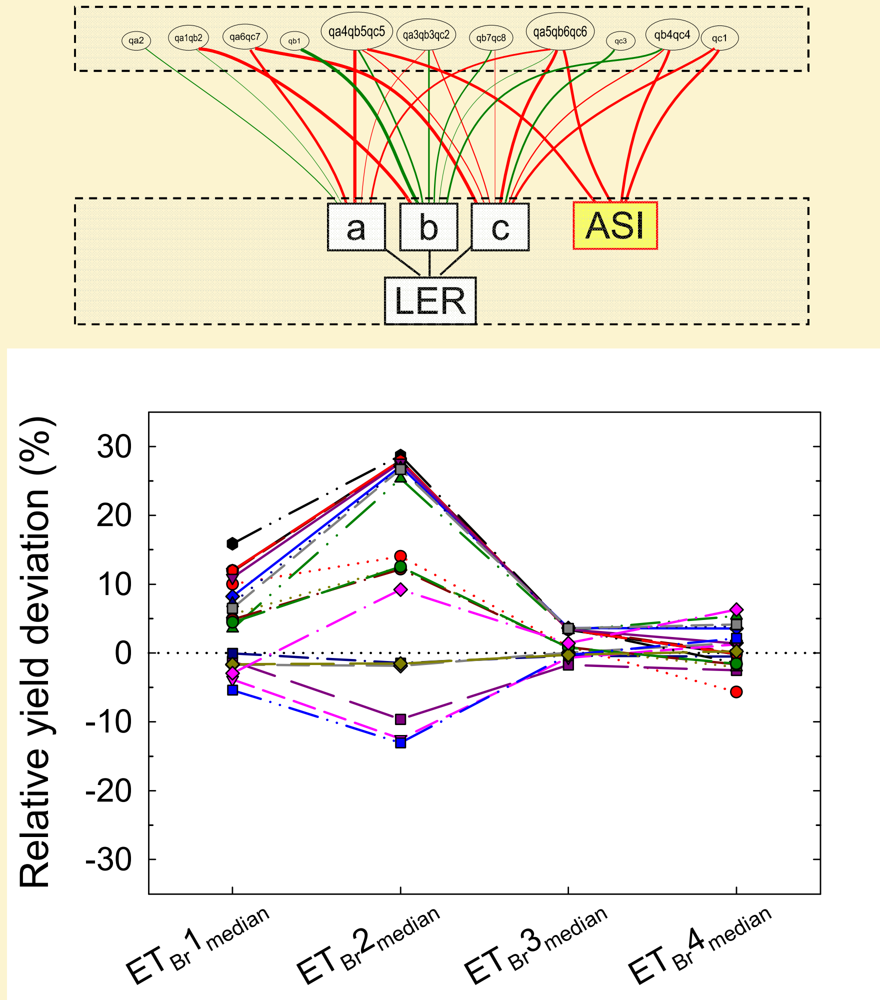
Population 1

QTL for leaf elong. parameters



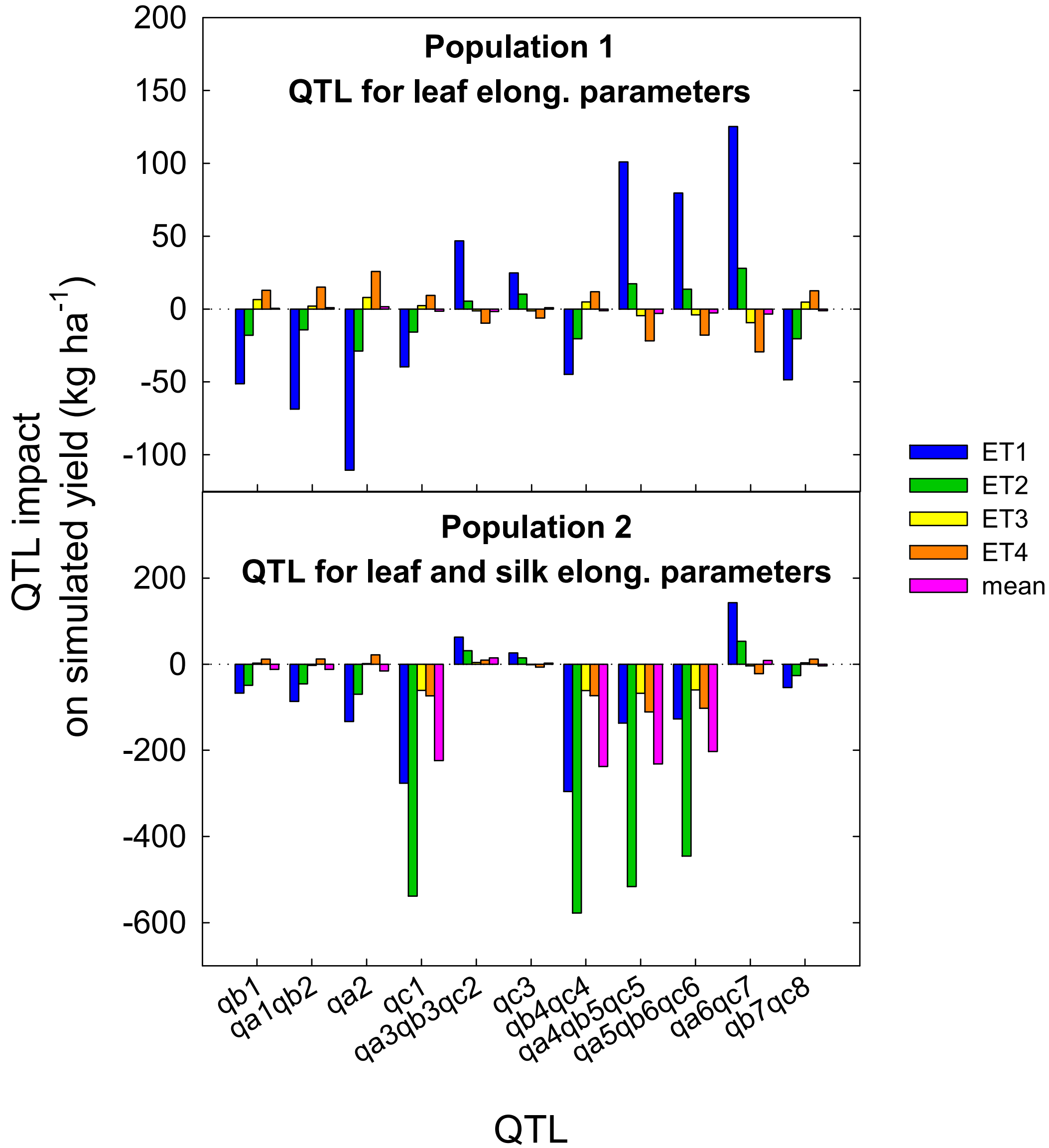
Population 2

QTL for leaf and silk elong. parameters



Chenu et al (2009) Genetics 183:1507-1523.

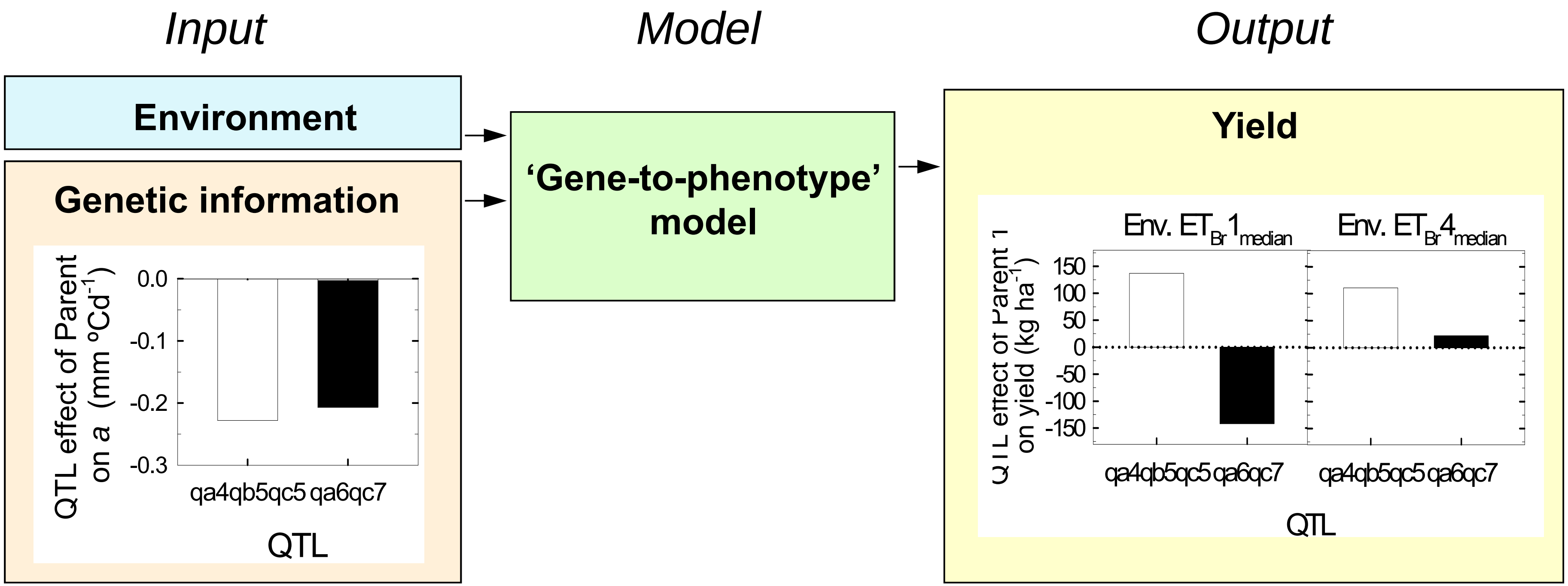
Effect of leaf and silk QTL on yield (Brazil)



- Effect of QTL opposite in ET1-2 and ET3-4.
- The mean effects of the QTL on yield
  - ranged from <10 to > 200 kg/ha
  - explained up to 30% of the variance for yield.
- The largest effects occurred when the QTL affecting ASI were included (graphs with different scales).

Very large effect in ET2 in pop2 (specific to the timing of the stress).

Estimation of the yield impact of organ-level QTL

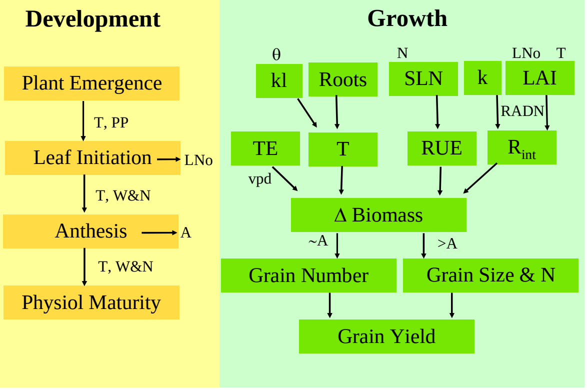


The effect of single QTLs with similar effect on leaf growth may have substantially different effects on yield in different environments

Chenu et al (2009) Genetics 183:1507-1523.

II - Connecting understanding of traits

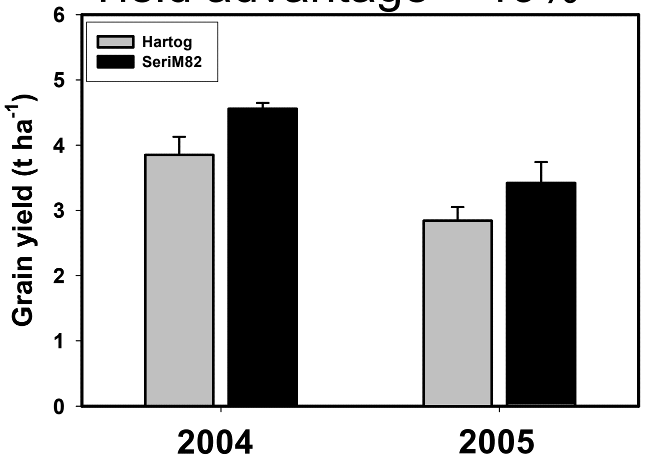
- Root architecture and staygreen in wheat -



Connecting understanding of traits
– Example of wheat root system architecture –

Drought adaptation in dryland wheat (G*E) for contrasting wheat varieties

Yield advantage = 19%

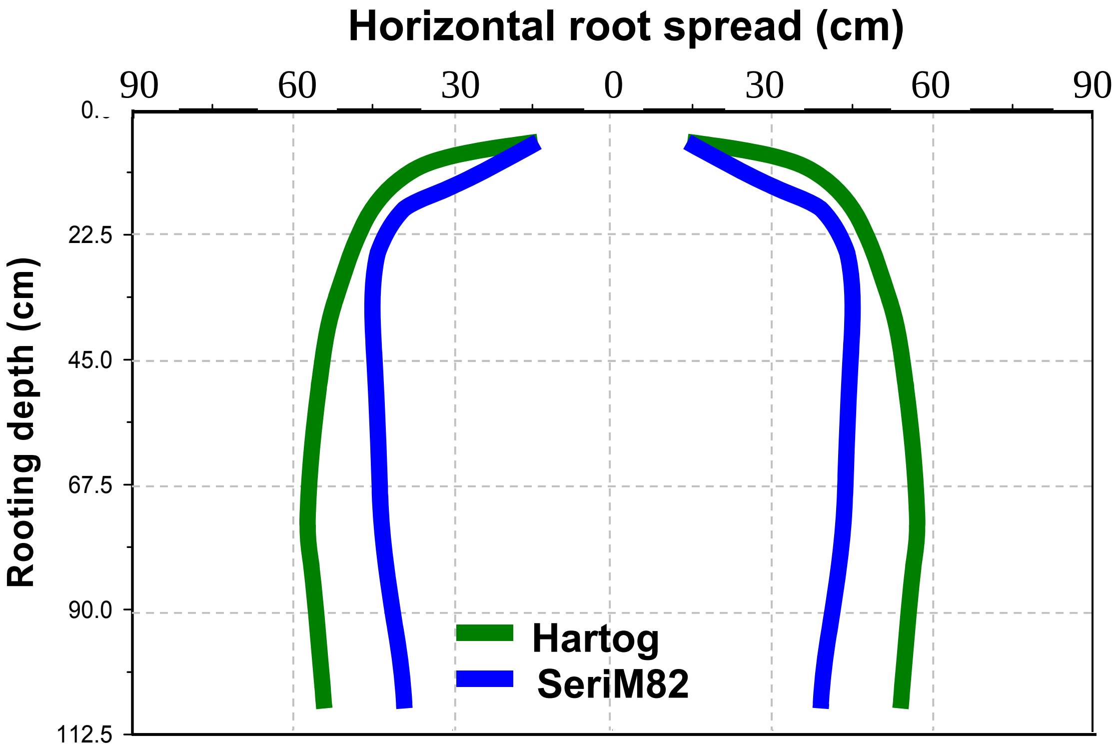


Staygreen phenotype

Christopher et al (2008) Aust J Agric Res

Connecting understanding of traits – Example of wheat root system architecture

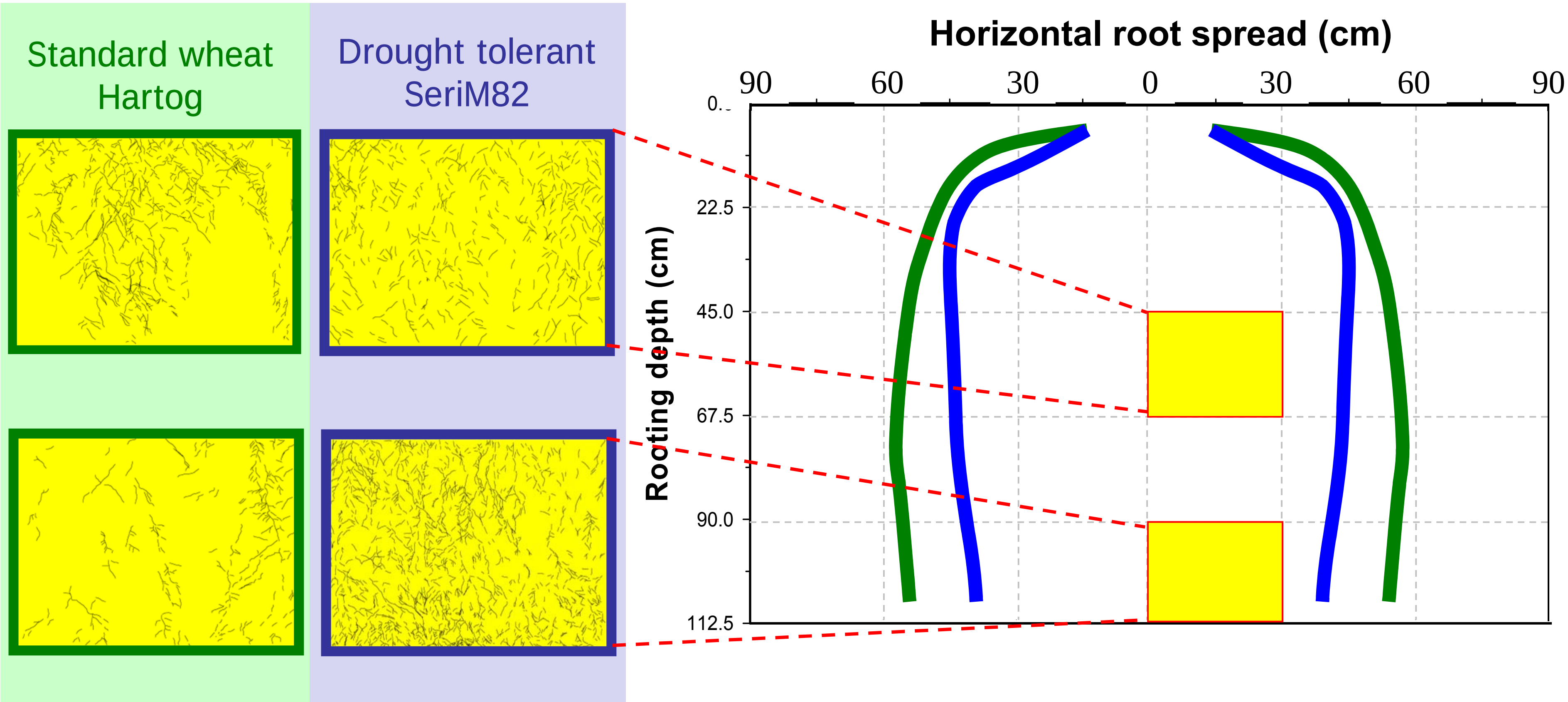
Controlled experiments => Seri has a root system more compact



Christopher et al (2008) Aust J Agric Res

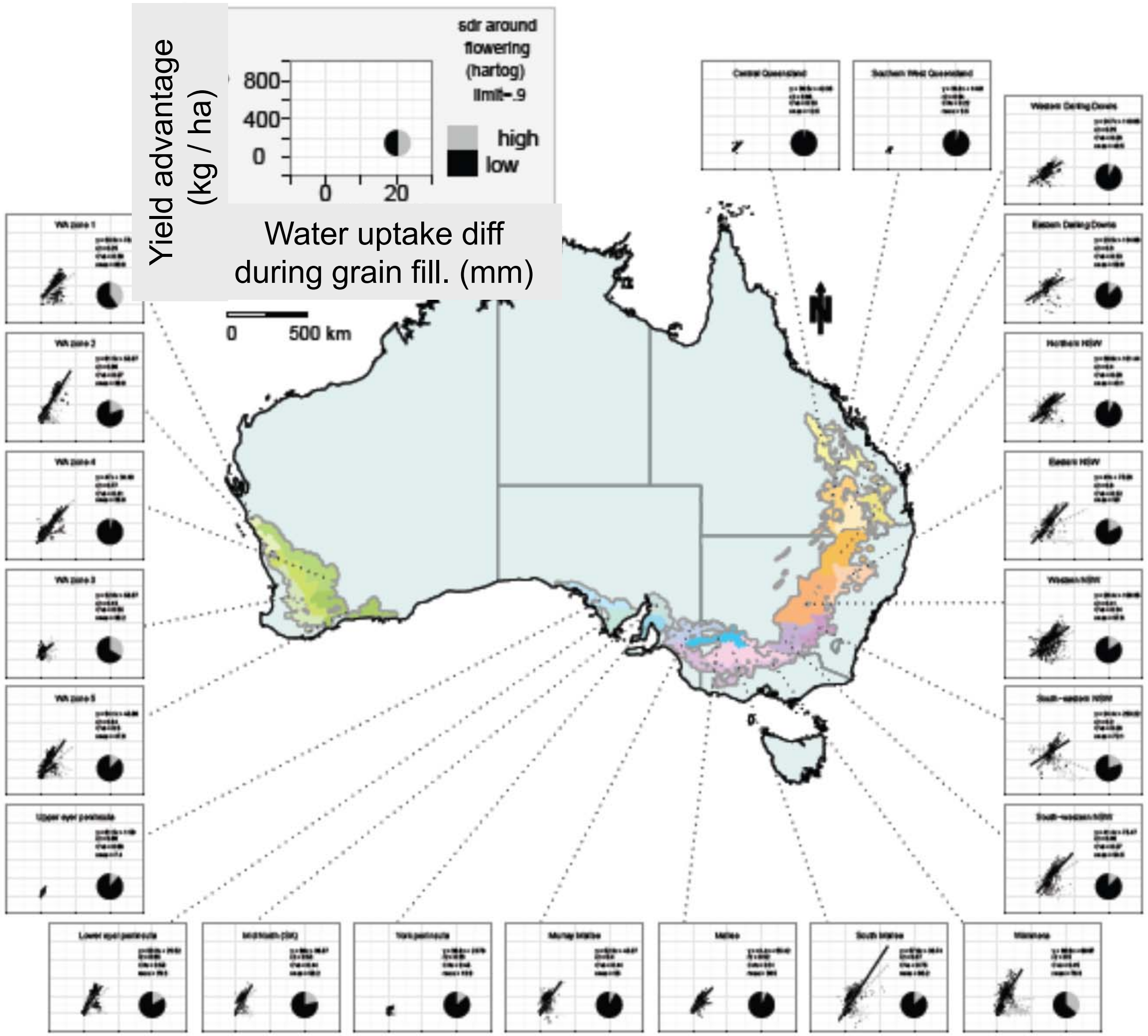
Connecting understanding of traits – Example of wheat root system architecture

Controlled experiments => Seri has - a root system more compact
- a better "occupancy" at depth



Manschadi et al (2006) Functional Plant Biol

Simulated effect of root traits modification on wheat yield



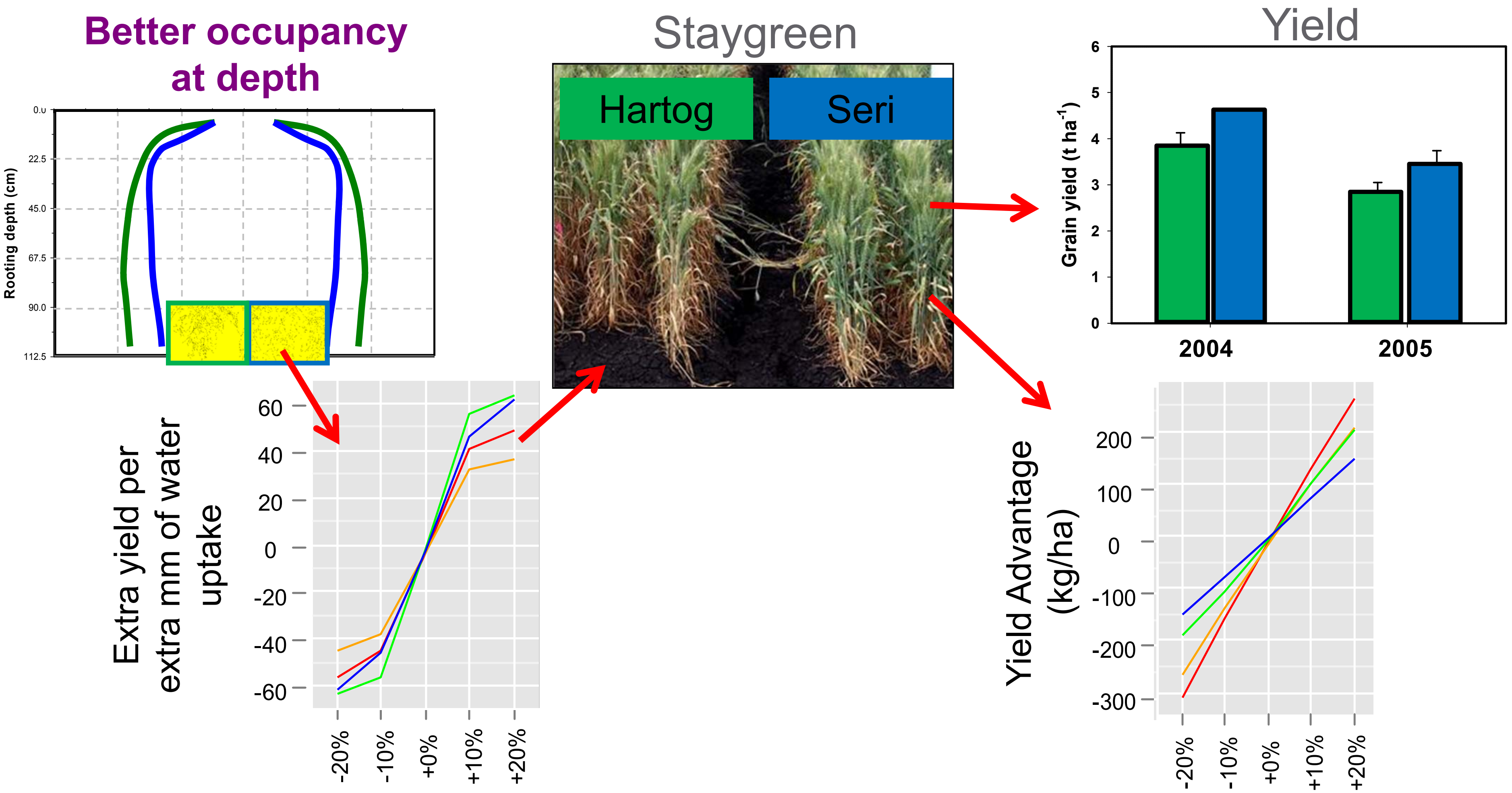
Root archi. with better water extraction at depth

⇒ ↗ yield gain

⇒ 18.7 kg ha^{-1} for every extra mm of water during the grain filling period

Chenu et al. unpublished

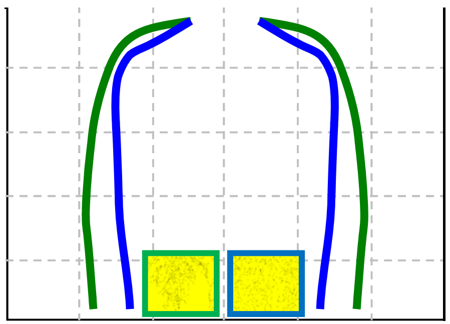
Involvement of roots in staygreen



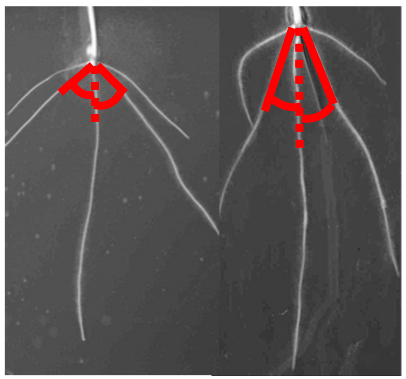
Genetic controls for root architecture

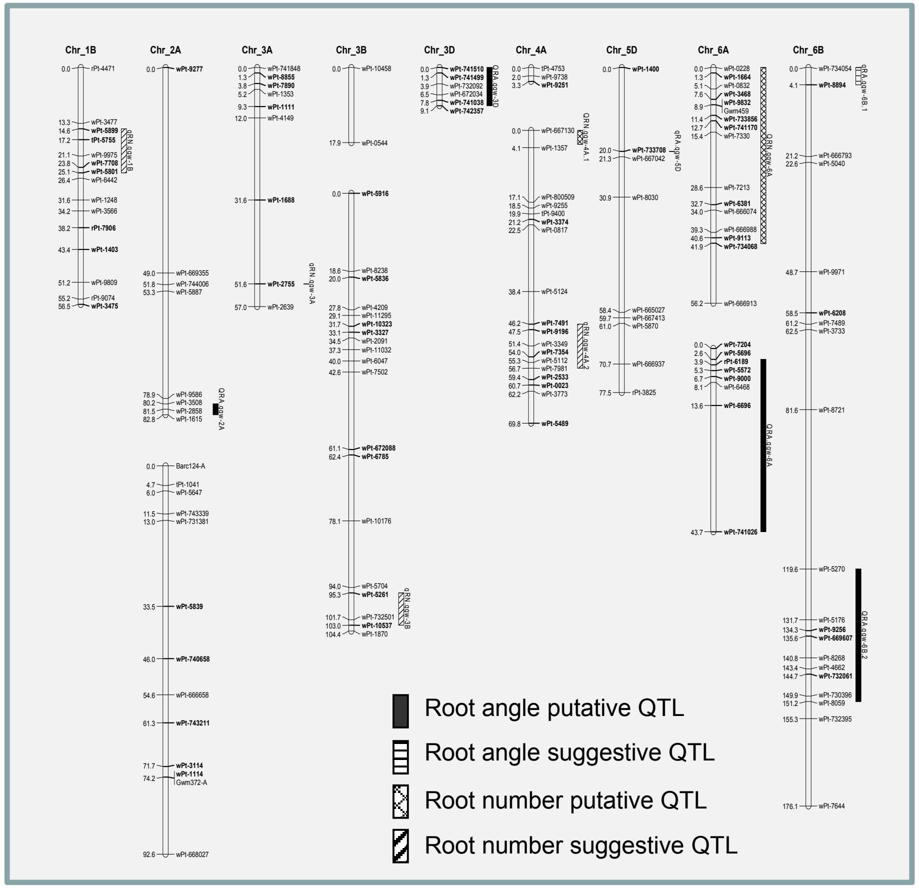
QTL identified using root angle and root number of seedling as a proxy

Better occupancy at depth



Hartog SeriM82

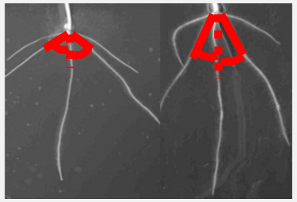




Manschadi A M, et al (2008) Plant and Soil
Christopher et al (2013) TAG 126:1563

Involvement of roots in staygreen

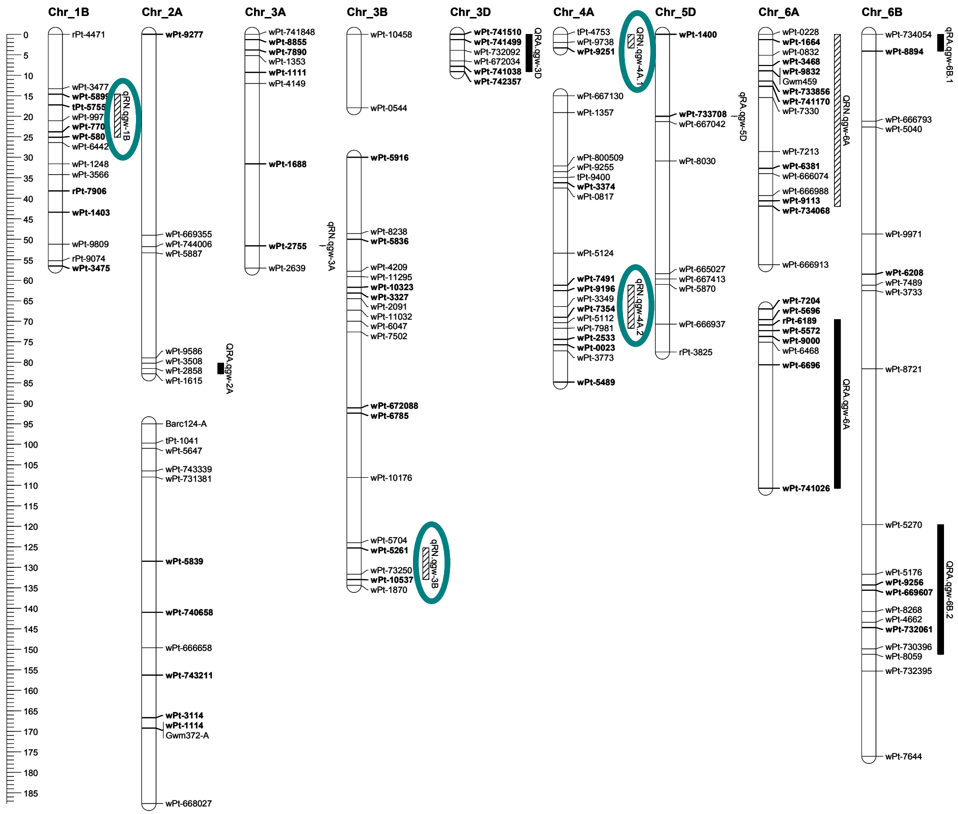
Roots



- Root angle putative QTL
- Root angle suggestive QTL
- Root number putative QTL
- Root number suggestive QTL

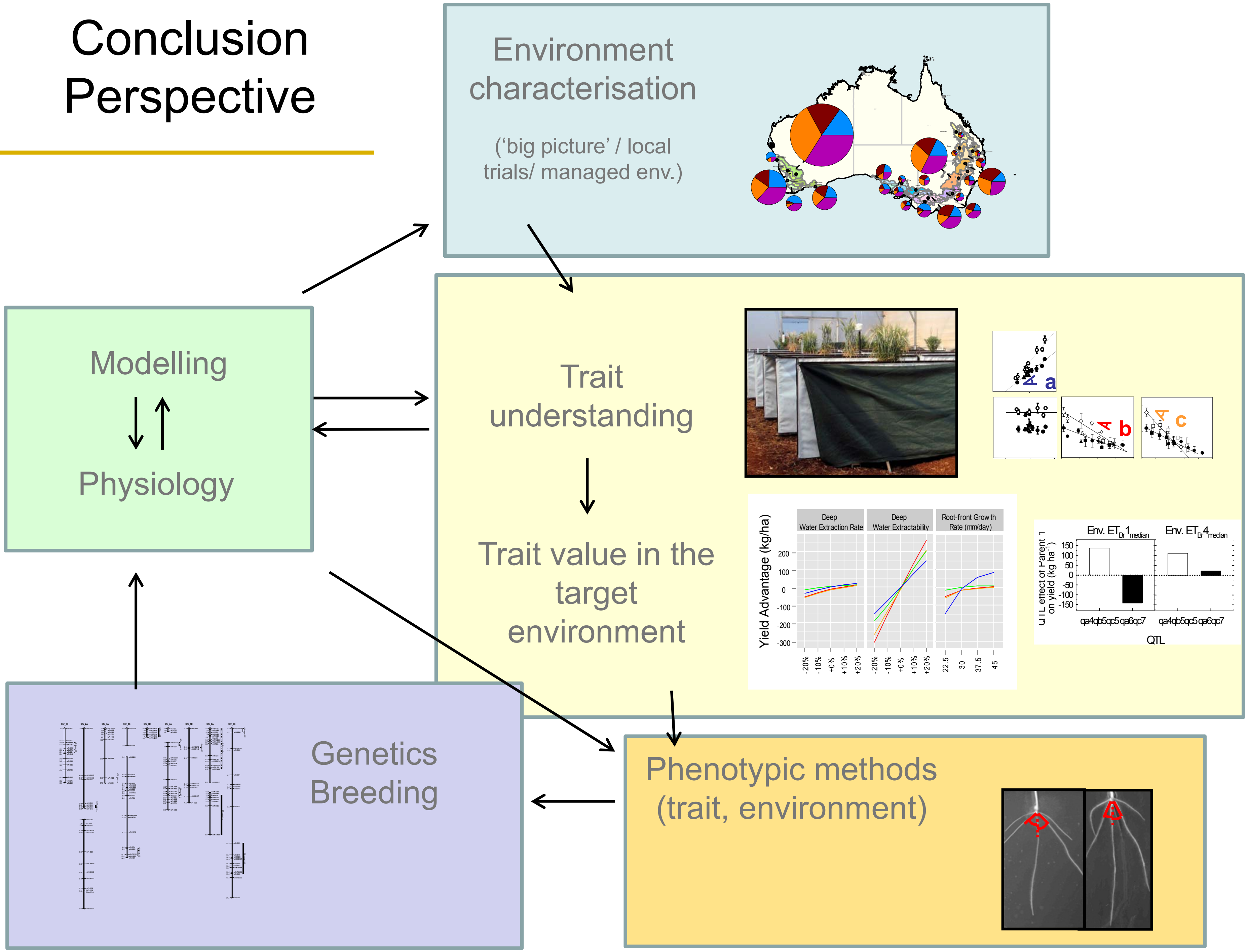
Staygreen

Staygreen & Yield QTL



Christopher et al (2013) TAG 126:1563

Conclusion Perspective



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Generation
Cultivating Plant Diversity for resource poor

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CSIRO

APSRU